Institut de Ciències del Cosmos
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The Milky Way as a case study for Galactic Dynamics

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Universitat de Barcelona

In collaboration with:
Teresa Antoja, Alexandra Girón Soto, Chervin Laporte, GaiaUB group,
Walter Dehnen, Ralph Schönrich, Lia Athanassoula

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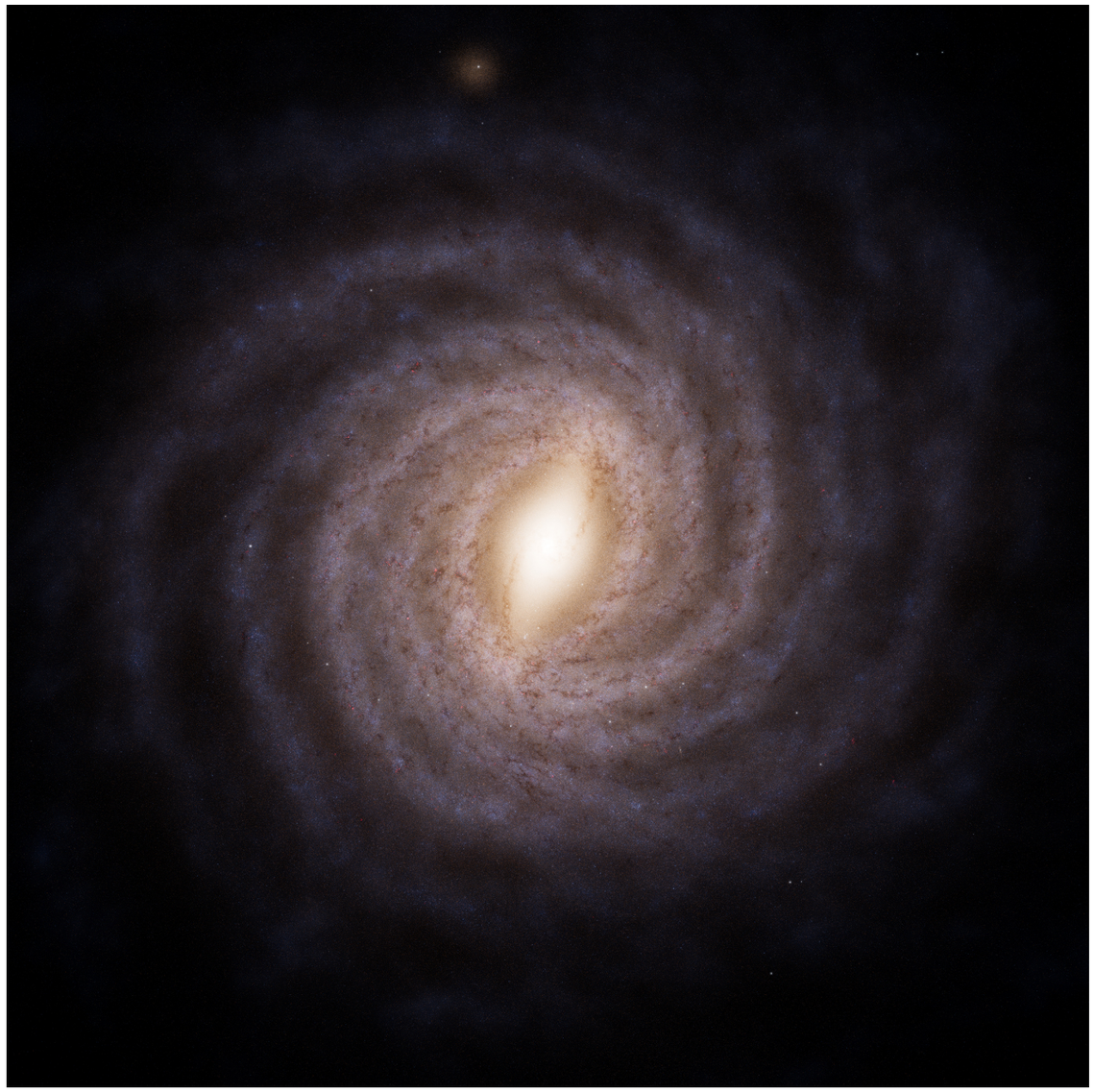
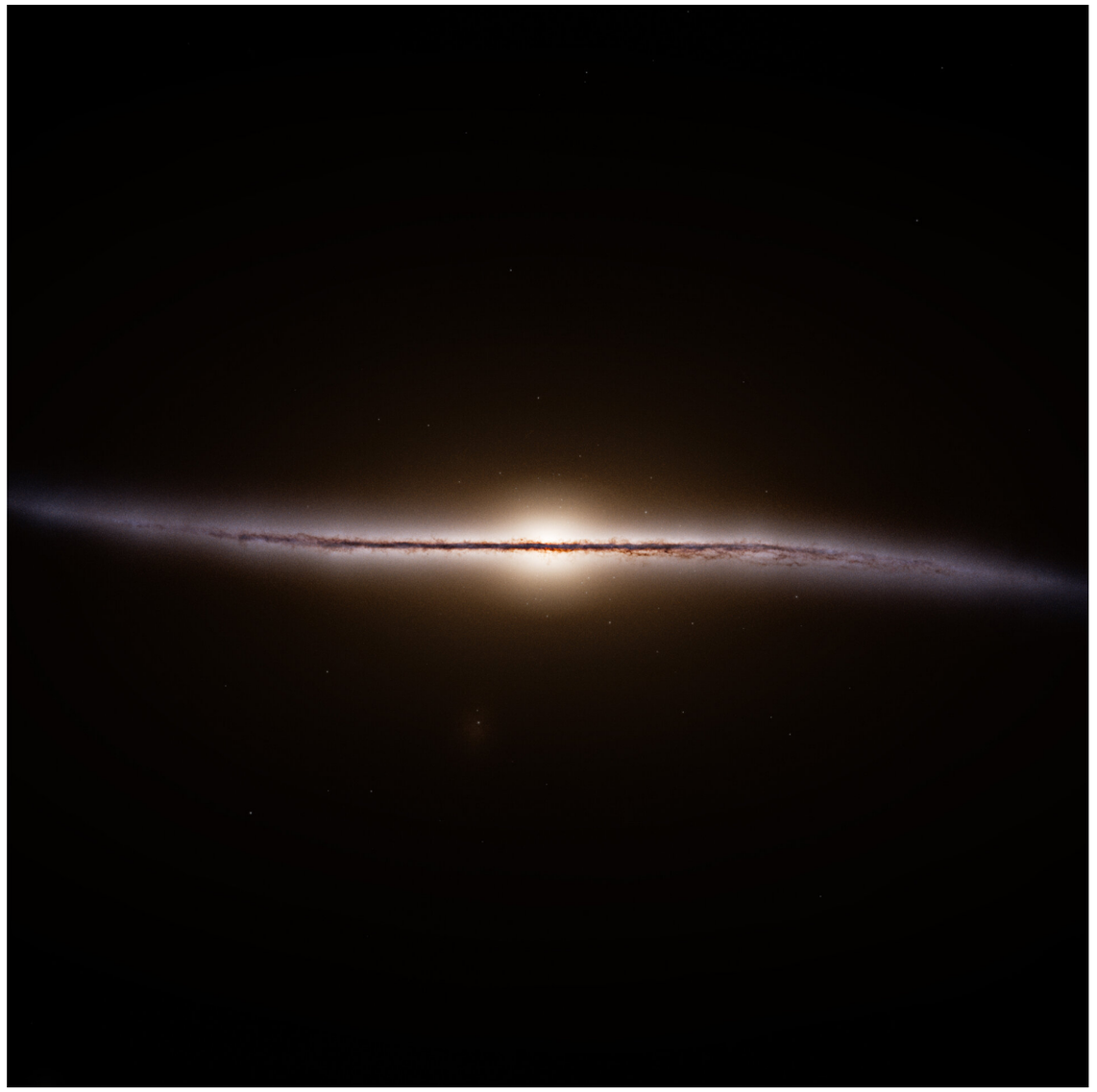
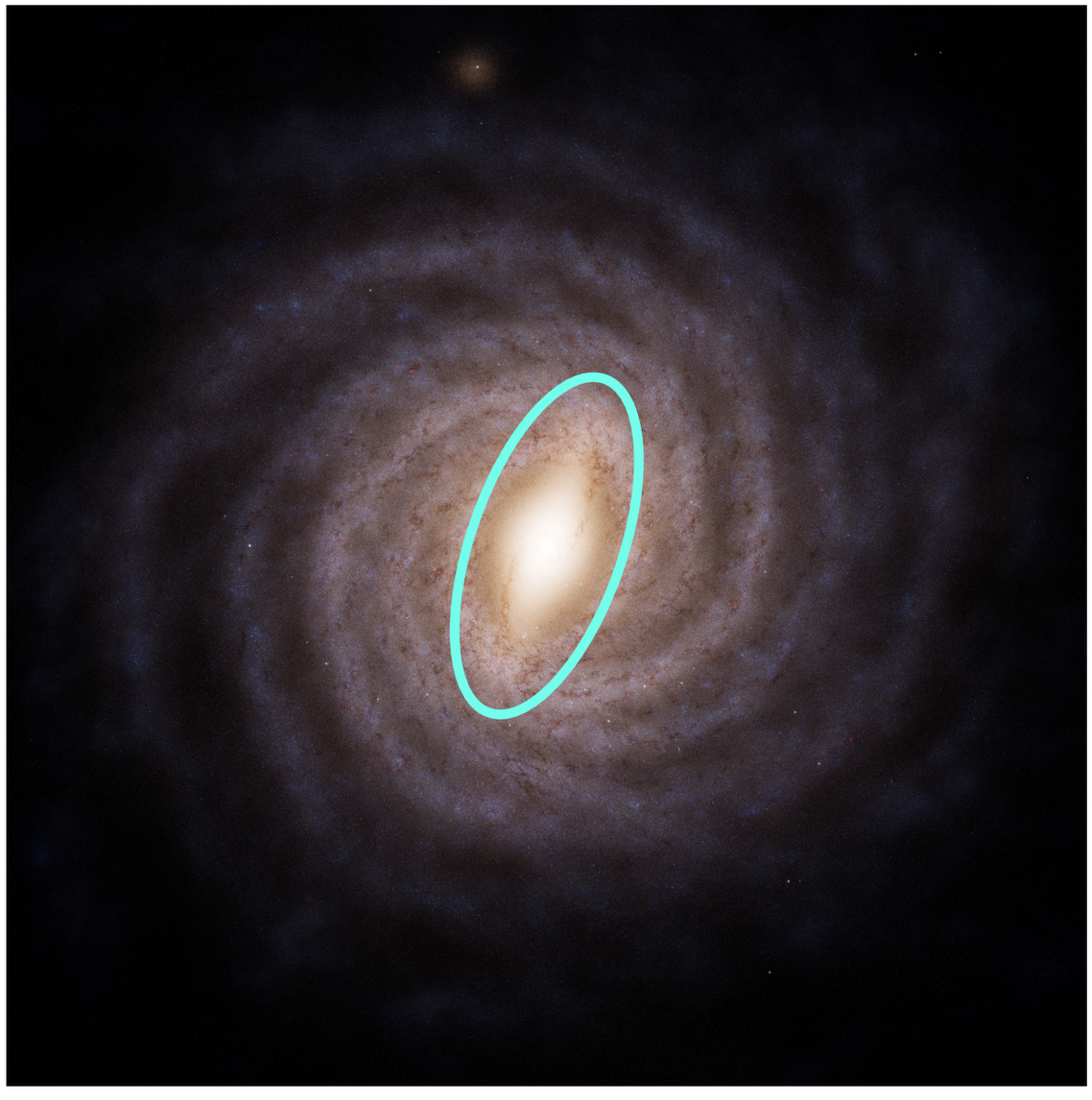
The Milky Way





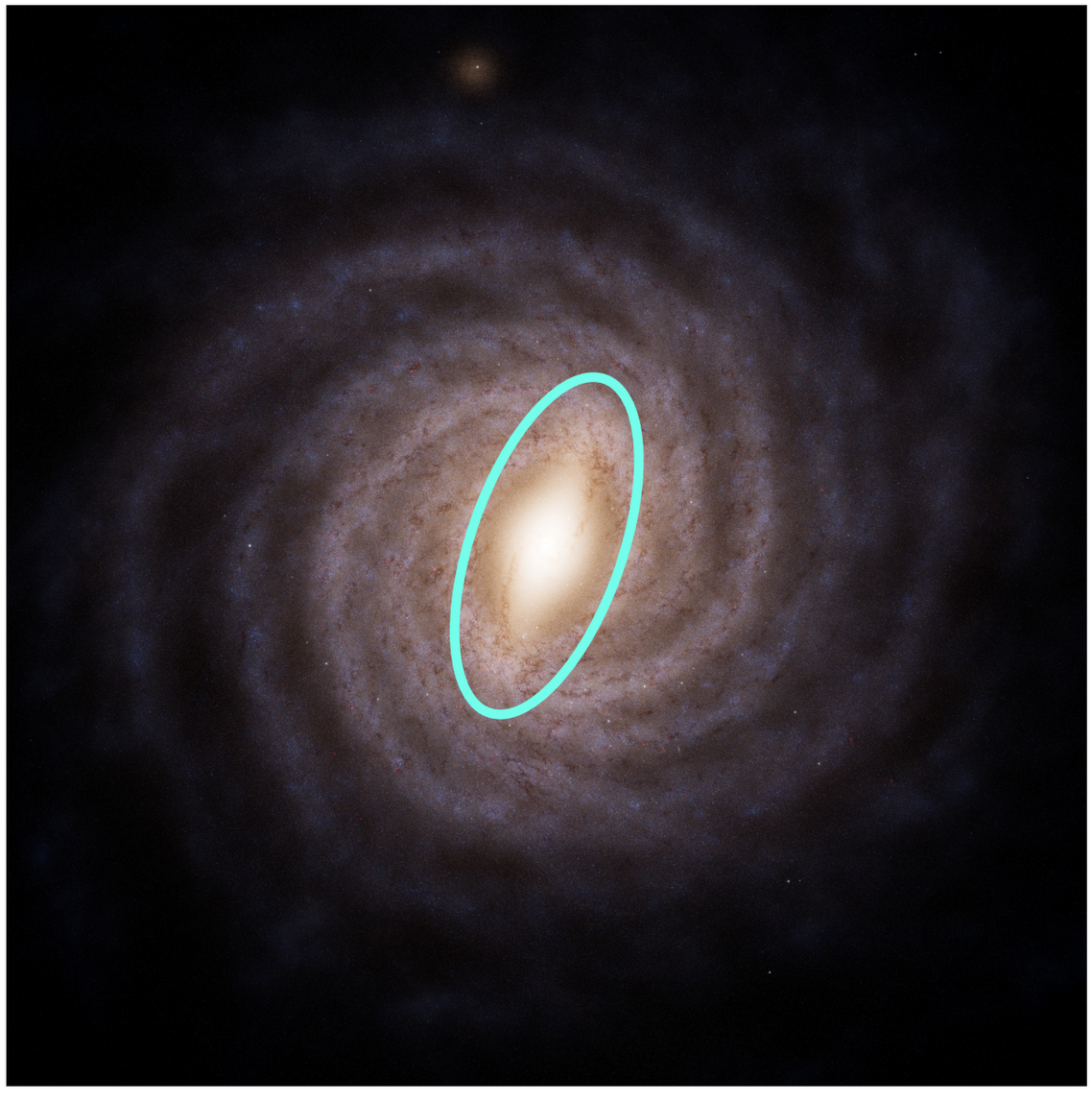
Most recent artist's impression of the Milky Way (credit: ESA/Gaia/DPAC, Stefan Payne-Wardenaar CC BY-SA 3.0 IGO or ESA standard License)

Galactic bar



- Gaia data broadens our knowledge of the bar

Galactic bar



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- Size: 3-5 kpc

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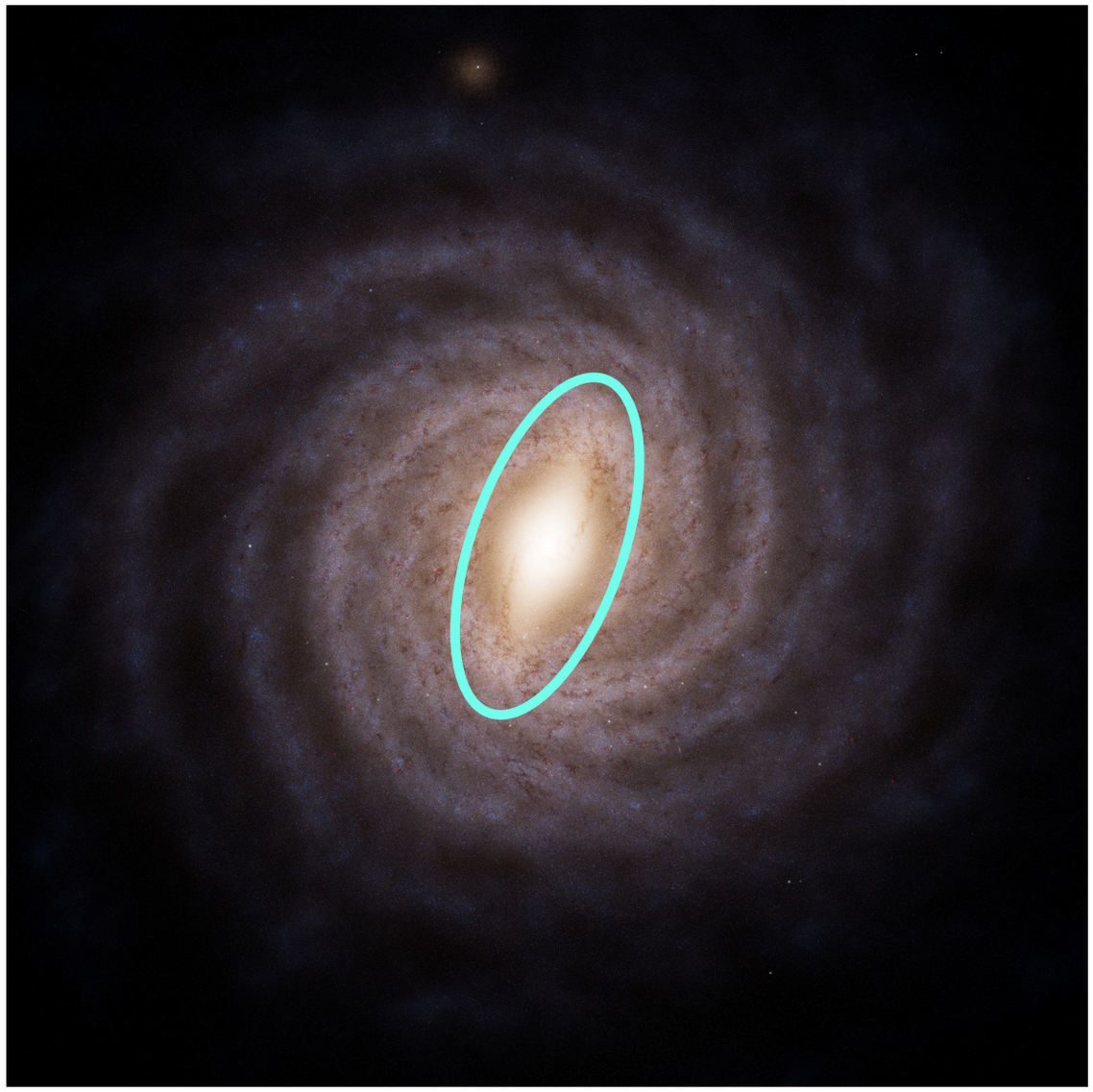

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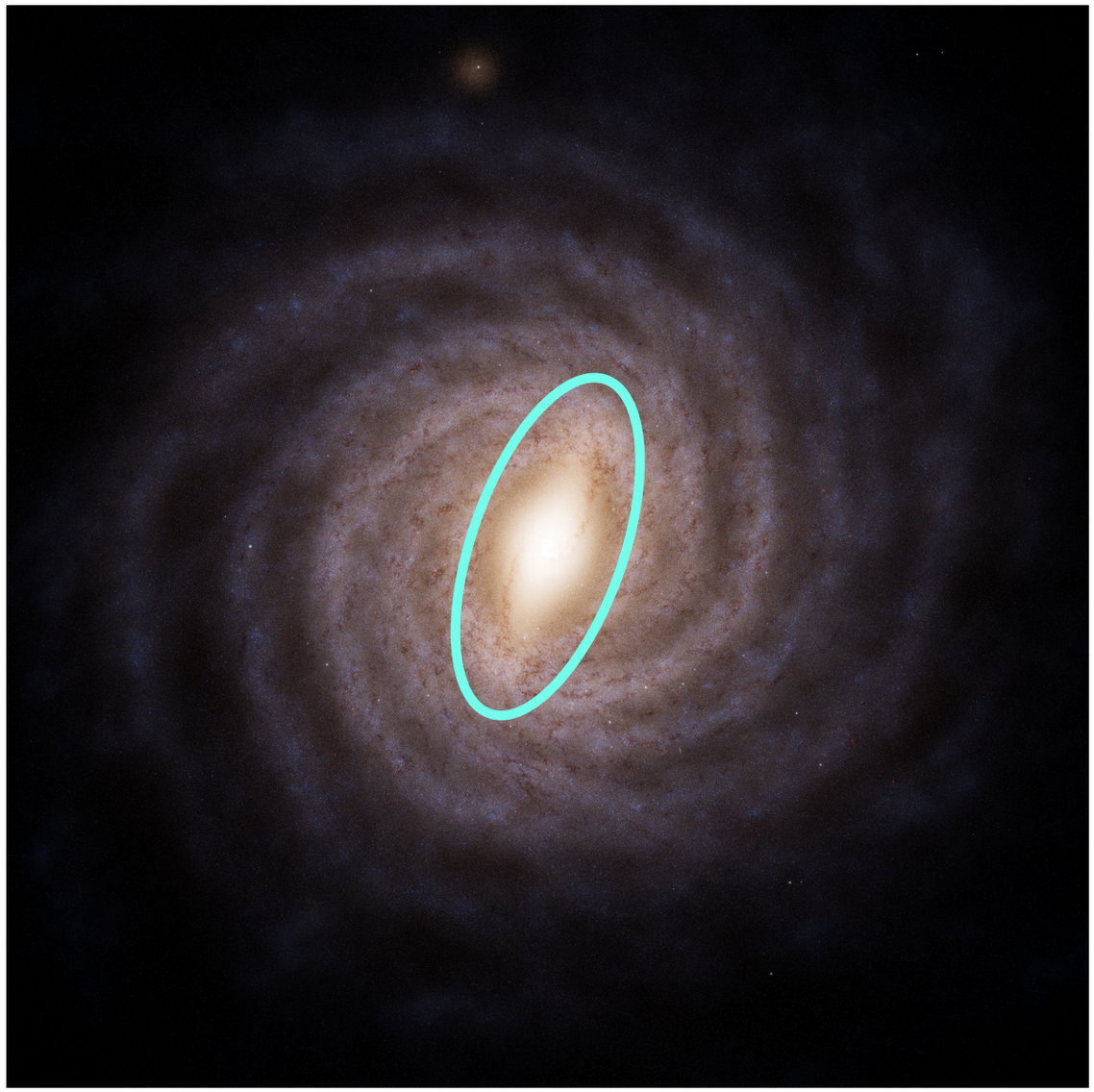
- Size: 3-5 kpc
- Rotation frequency = pattern speed: 30-50 1/Gyr (see a recent review of Hunt & Vasiliev 2025)

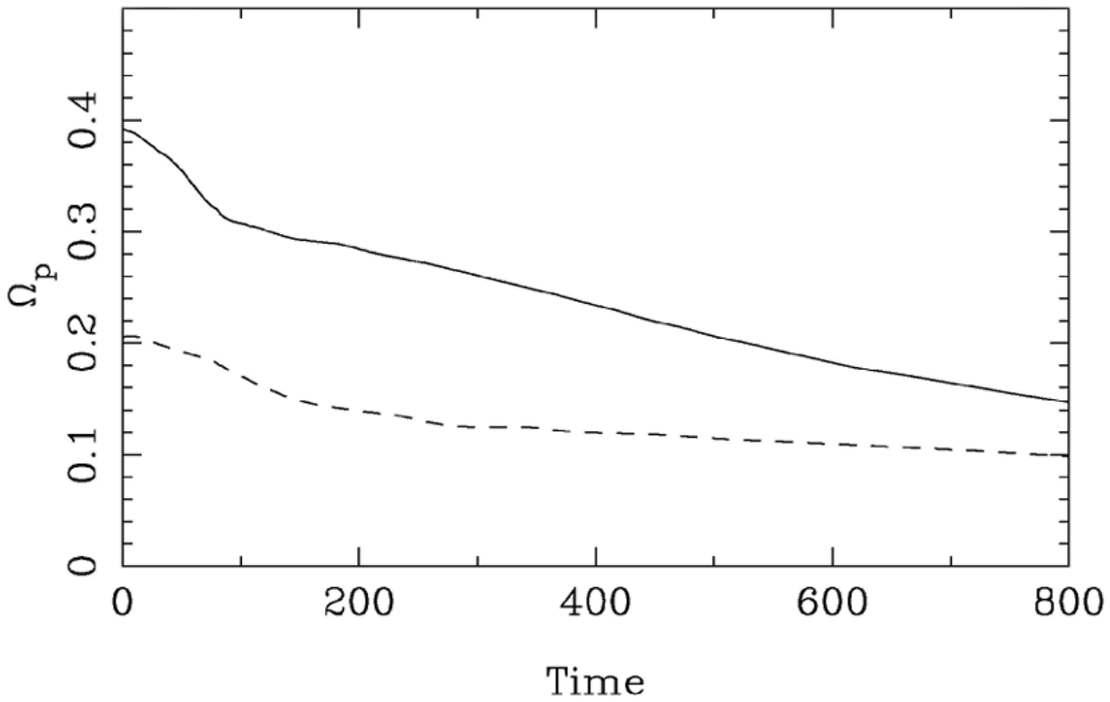
Galactic bar



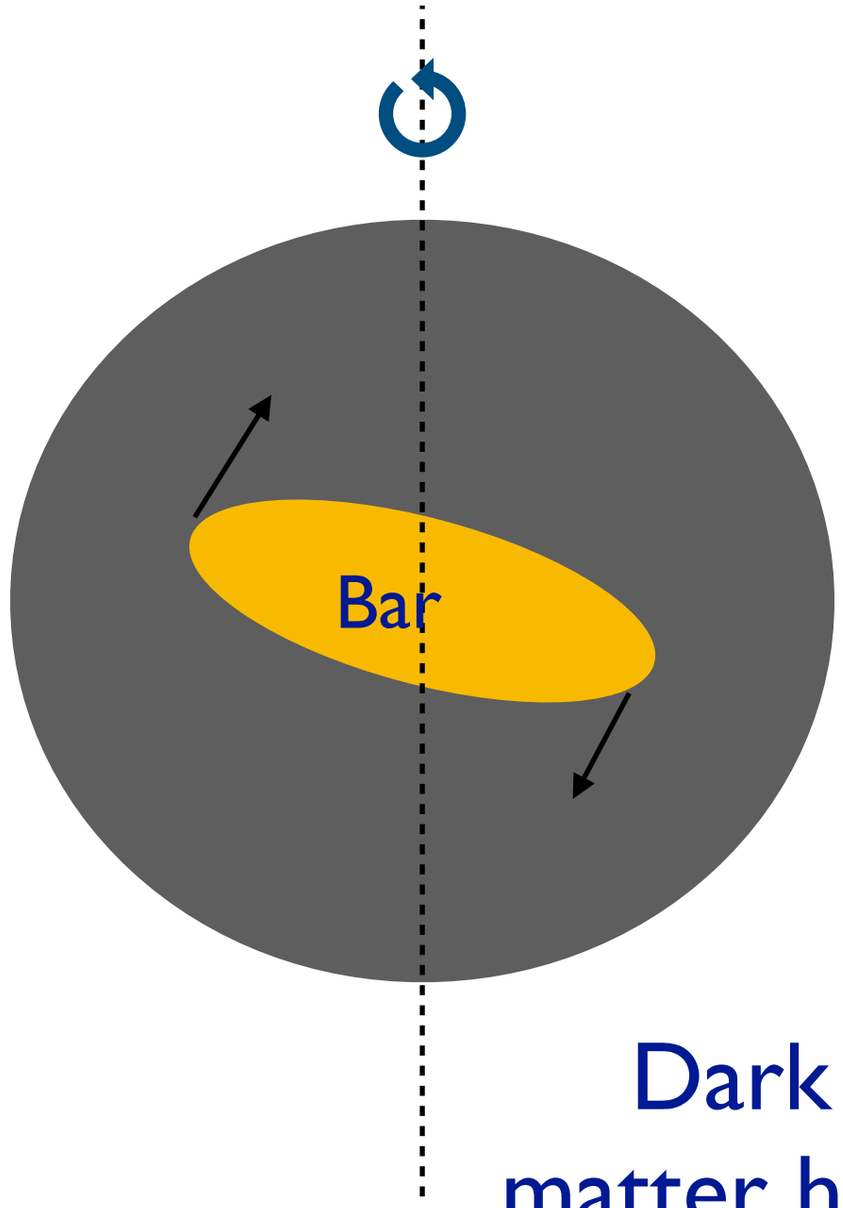
- Gaia data broadens our knowledge of the bar
- Size: 3-5 kpc
- Rotation frequency = pattern speed: 30-50 1/Gyr (see a recent review of Hunt & Vasiliev 2025)
- Appears to be slowing down (Chiba, Friske & Schönrich 2021)

Pattern speed of bars

- Bars slow down via dynamical friction in DM haloes (e.g. Sellwood & Weinberg 1980; Athanassoula 2003)



Athanassoula (2003)

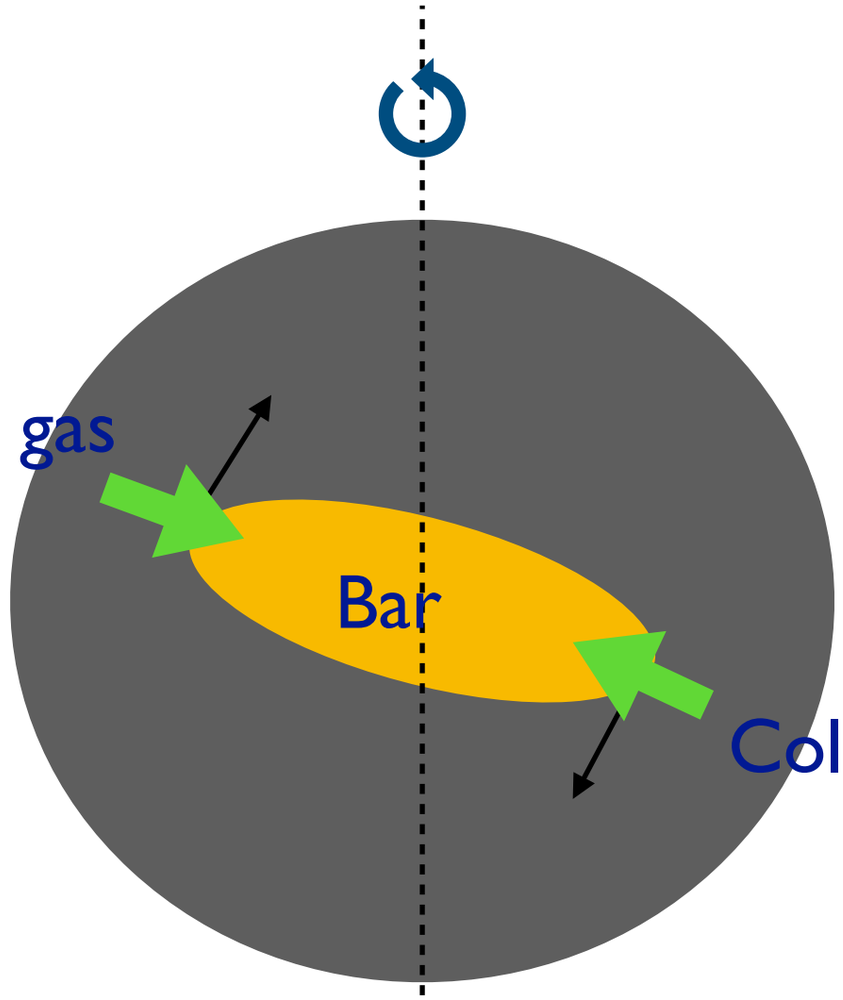


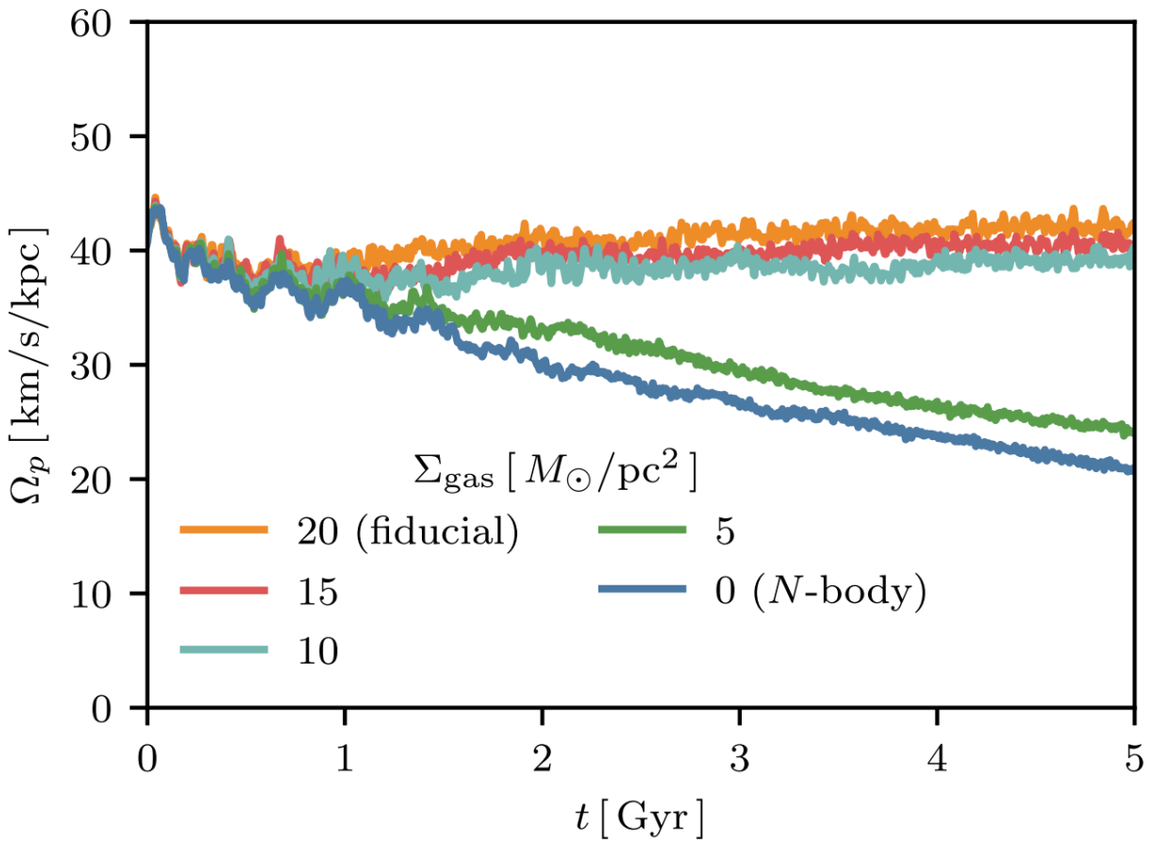
Dark matter halo

Pattern speed of bars

- Bars slow down via dynamical friction in DM haloes (e.g. Sellwood & Weinberg 1980; Athanassoula 2003)

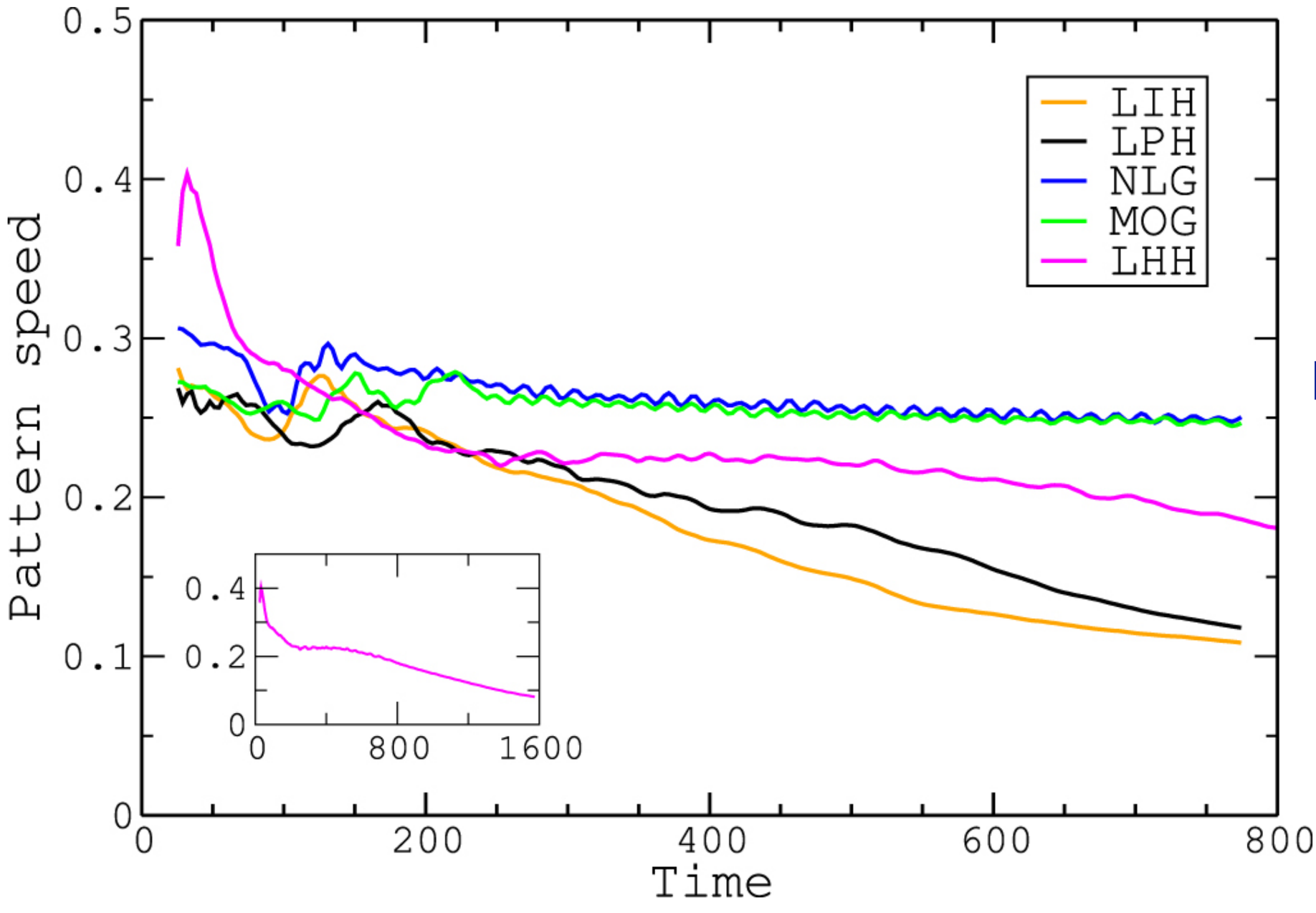
- Gas can stop or weaken the slowdown (e.g. Villa-Vargas et al. 2009, 2010; Athanassoula 2014; Beane et al. 2023)





Beane et al. (2023)

Pattern speed and dark matter



Modified gravity

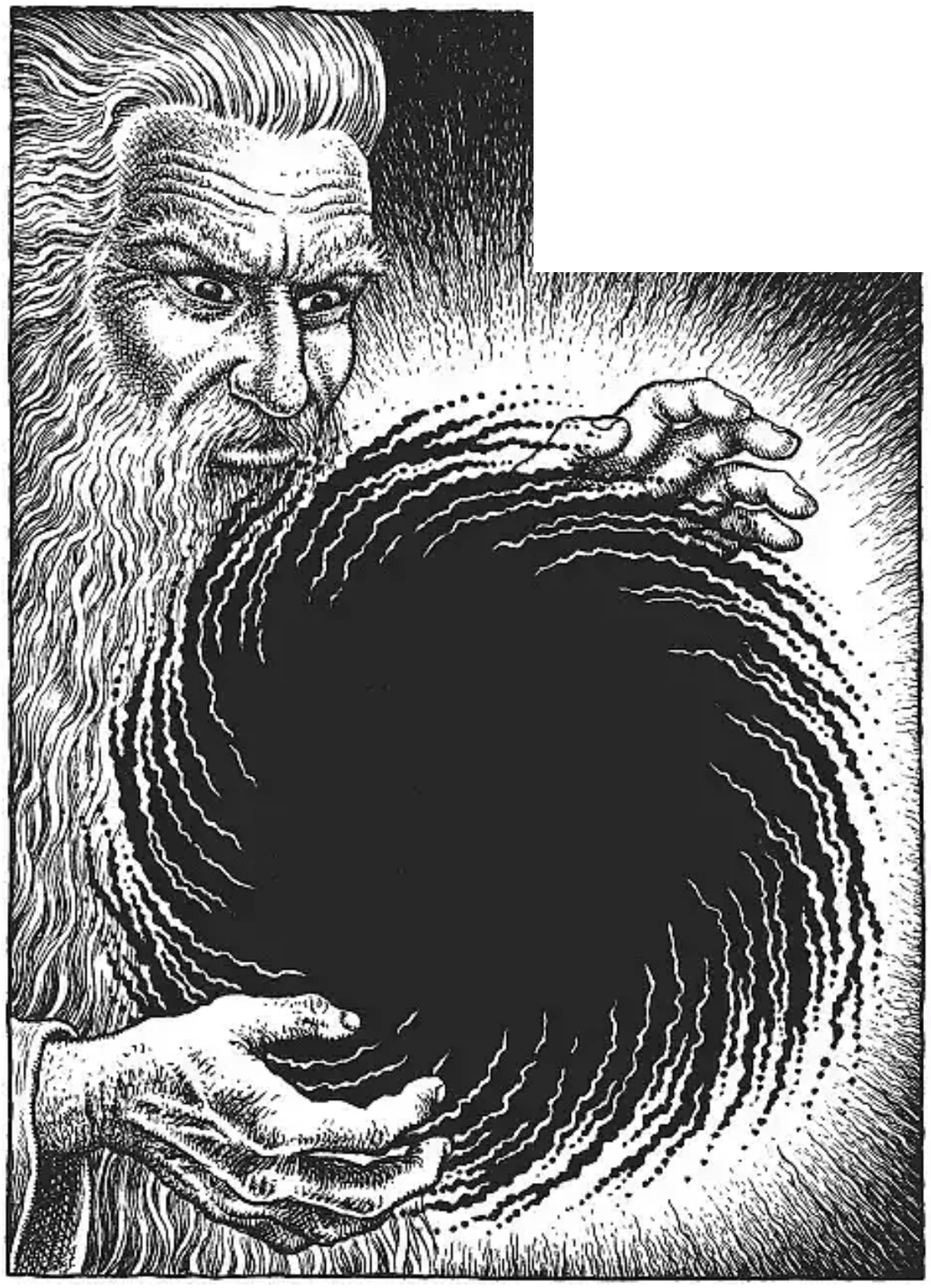
Dark matter

Ghafourian et al. (2020)

Tools of Galactic Dynamics

Classical:

Idealised N-body simulations, test particles, perturbation theory etc.



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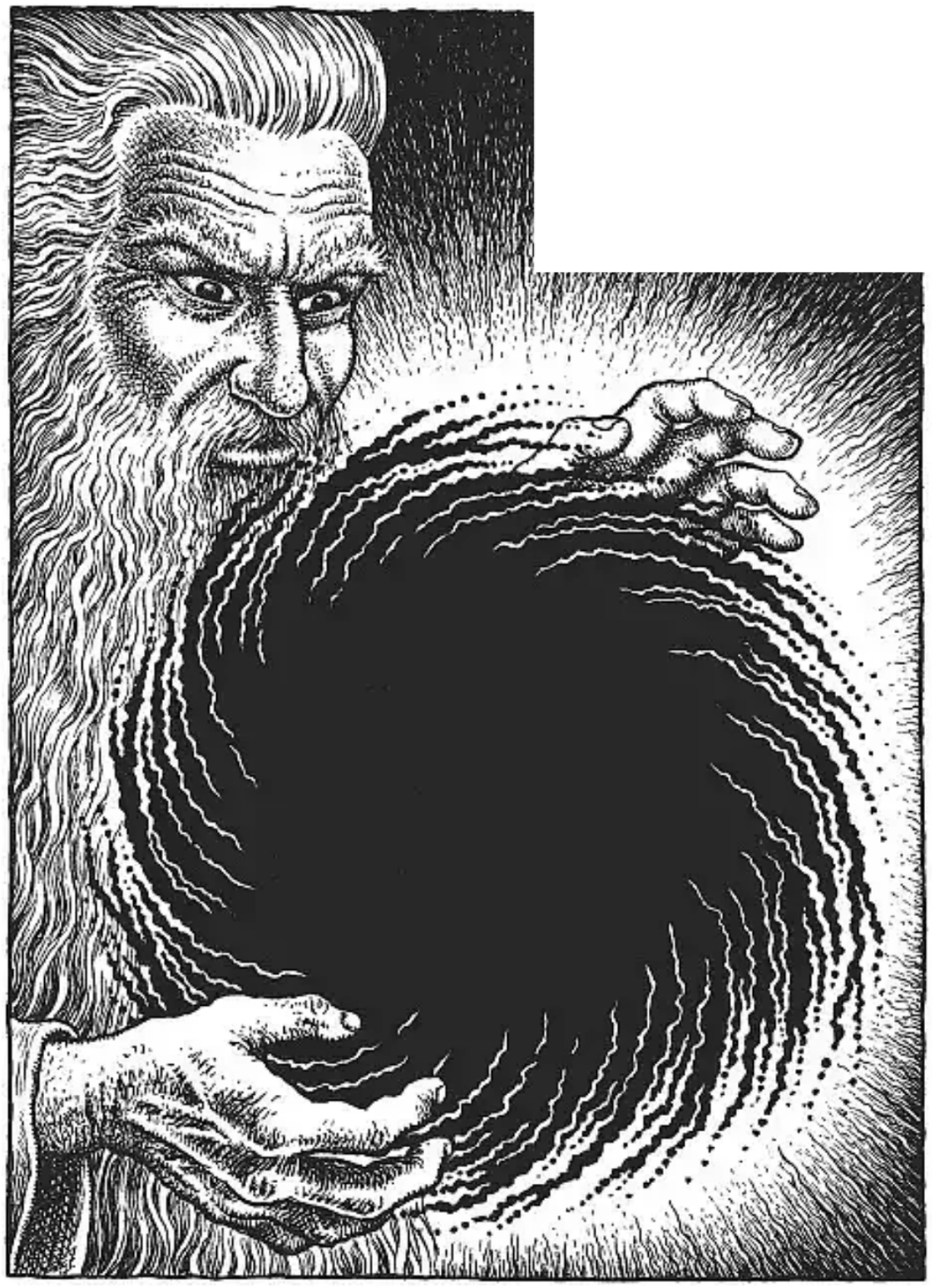
- Full control of the ingredients

- Simplicity



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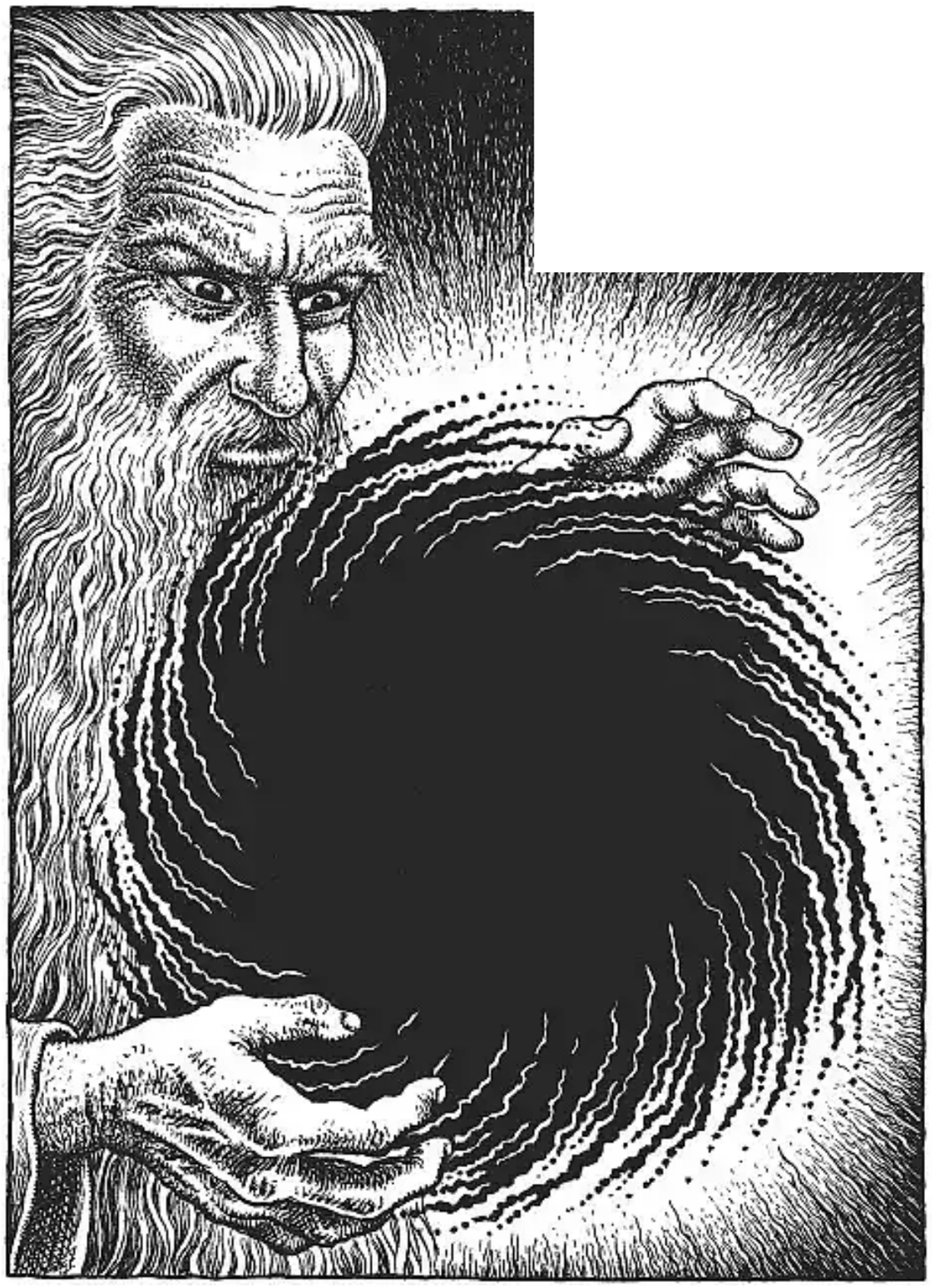

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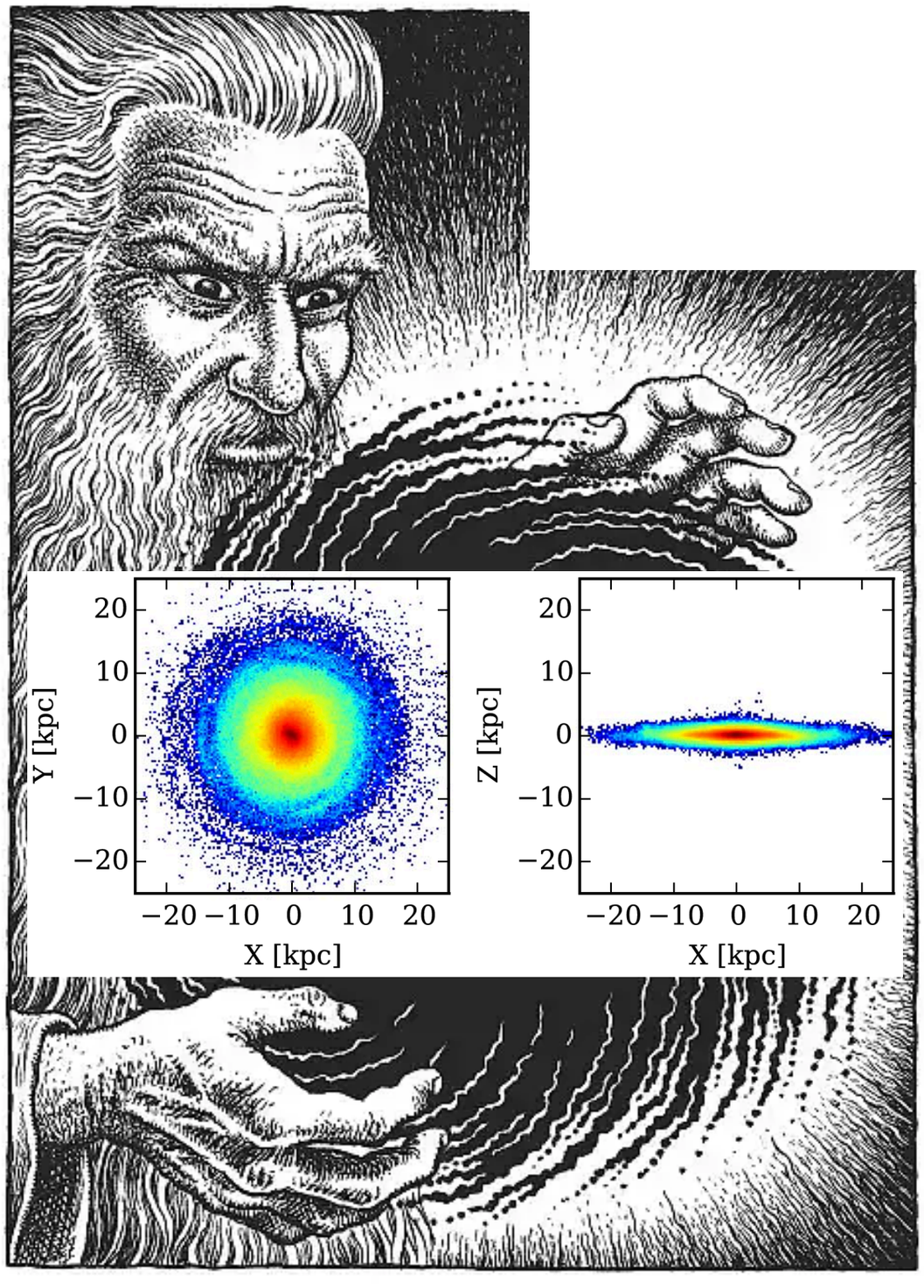

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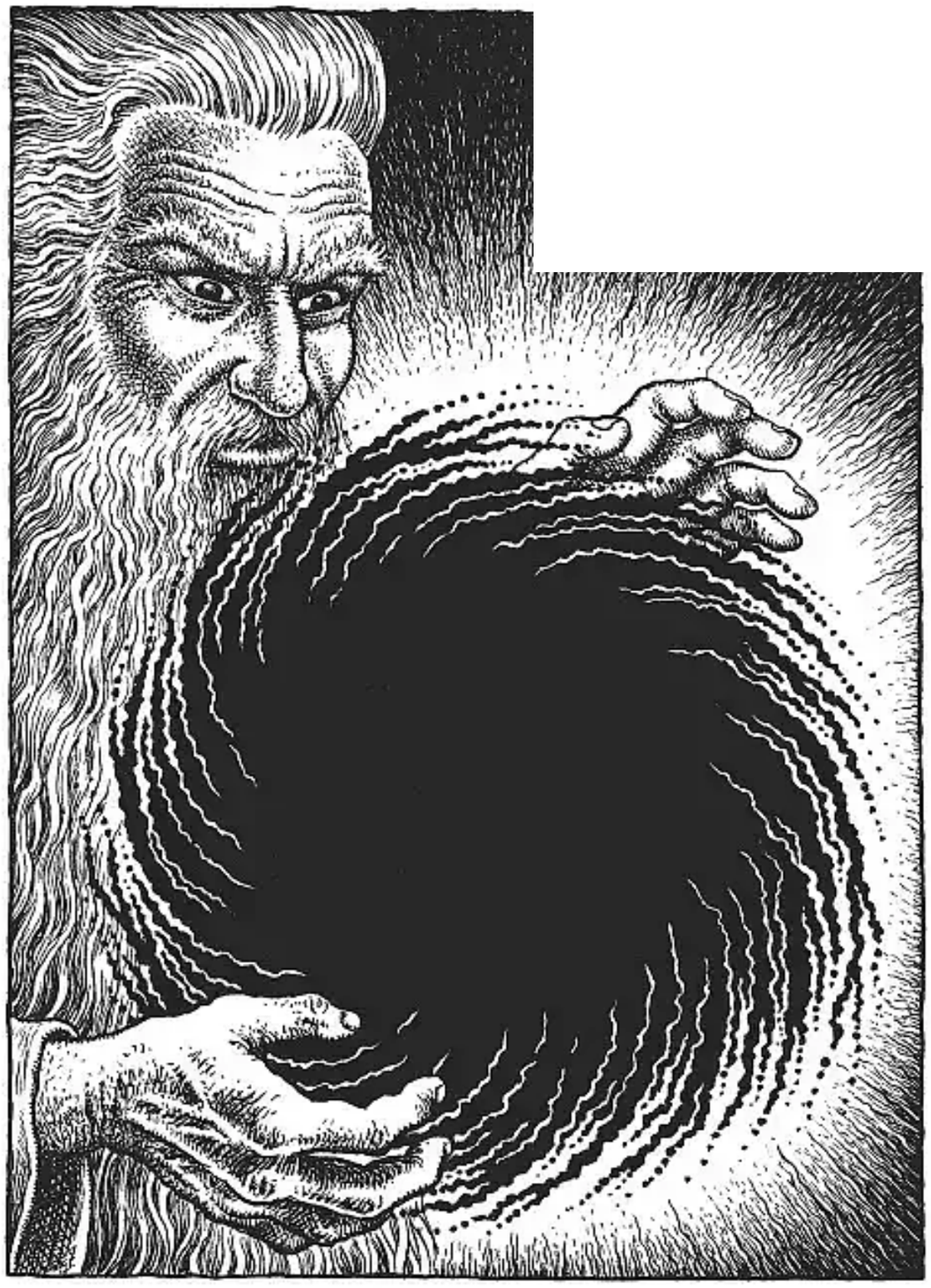
Population of galaxies in cosmological simulations, zoom-ins



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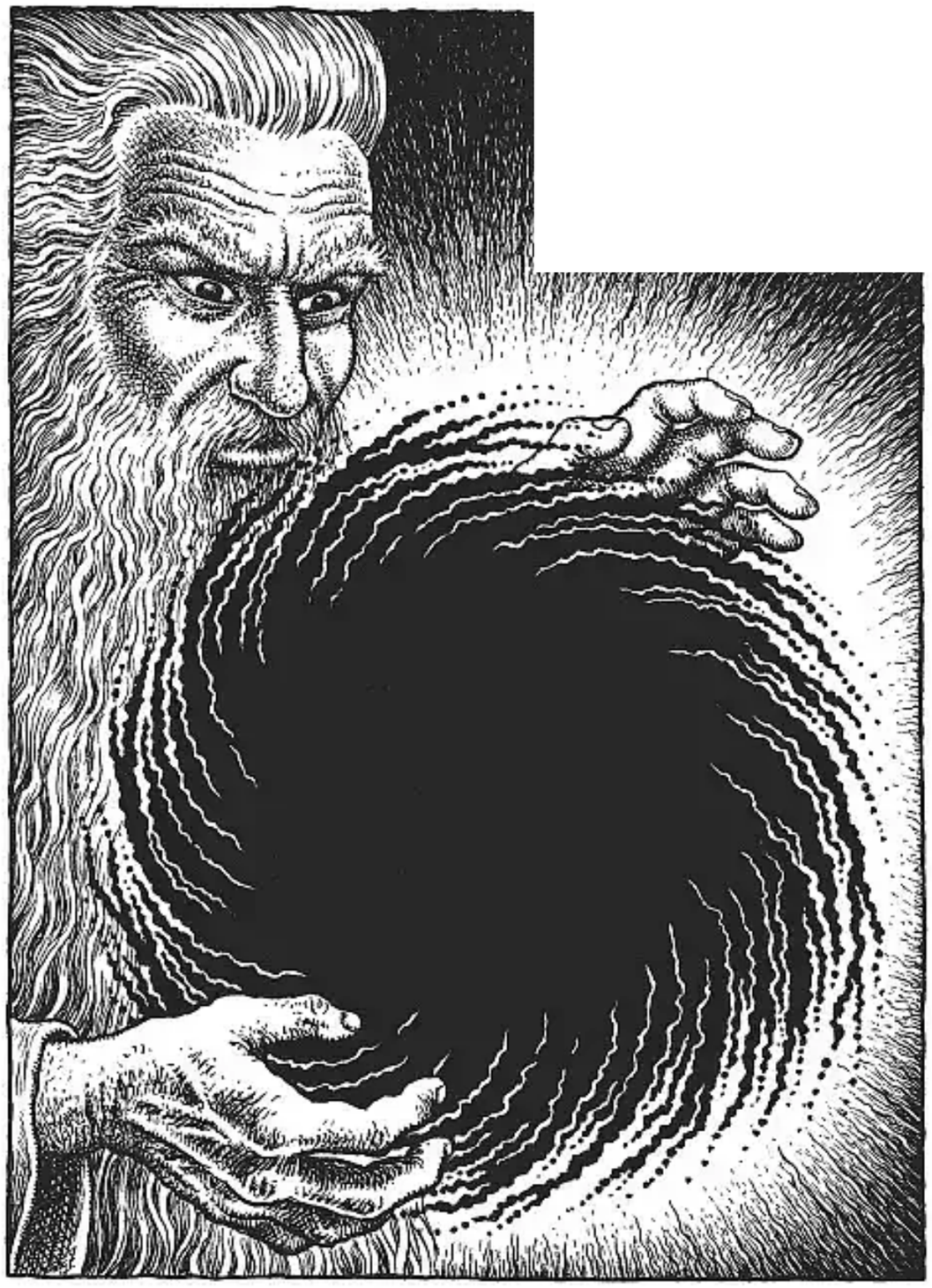

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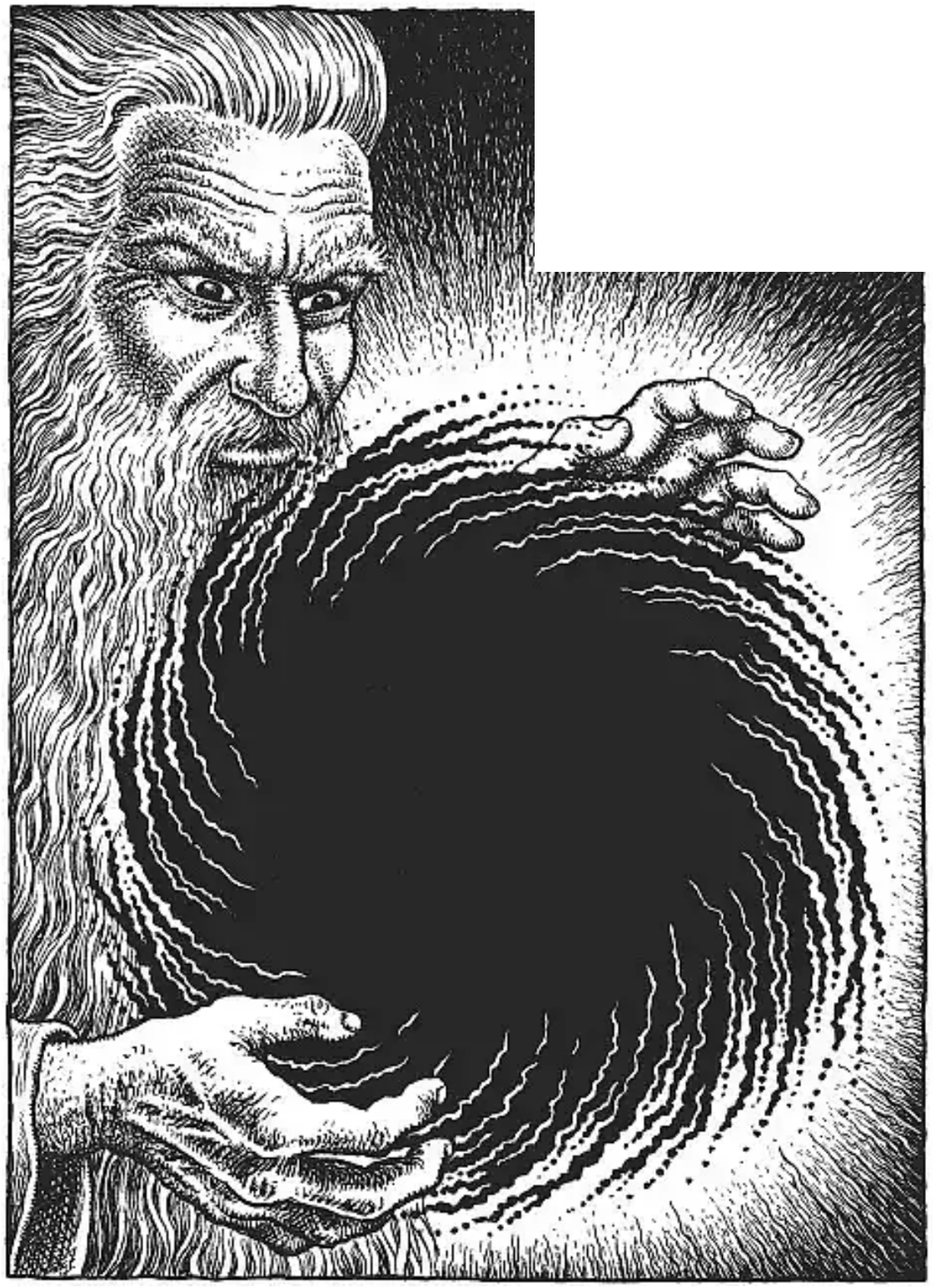

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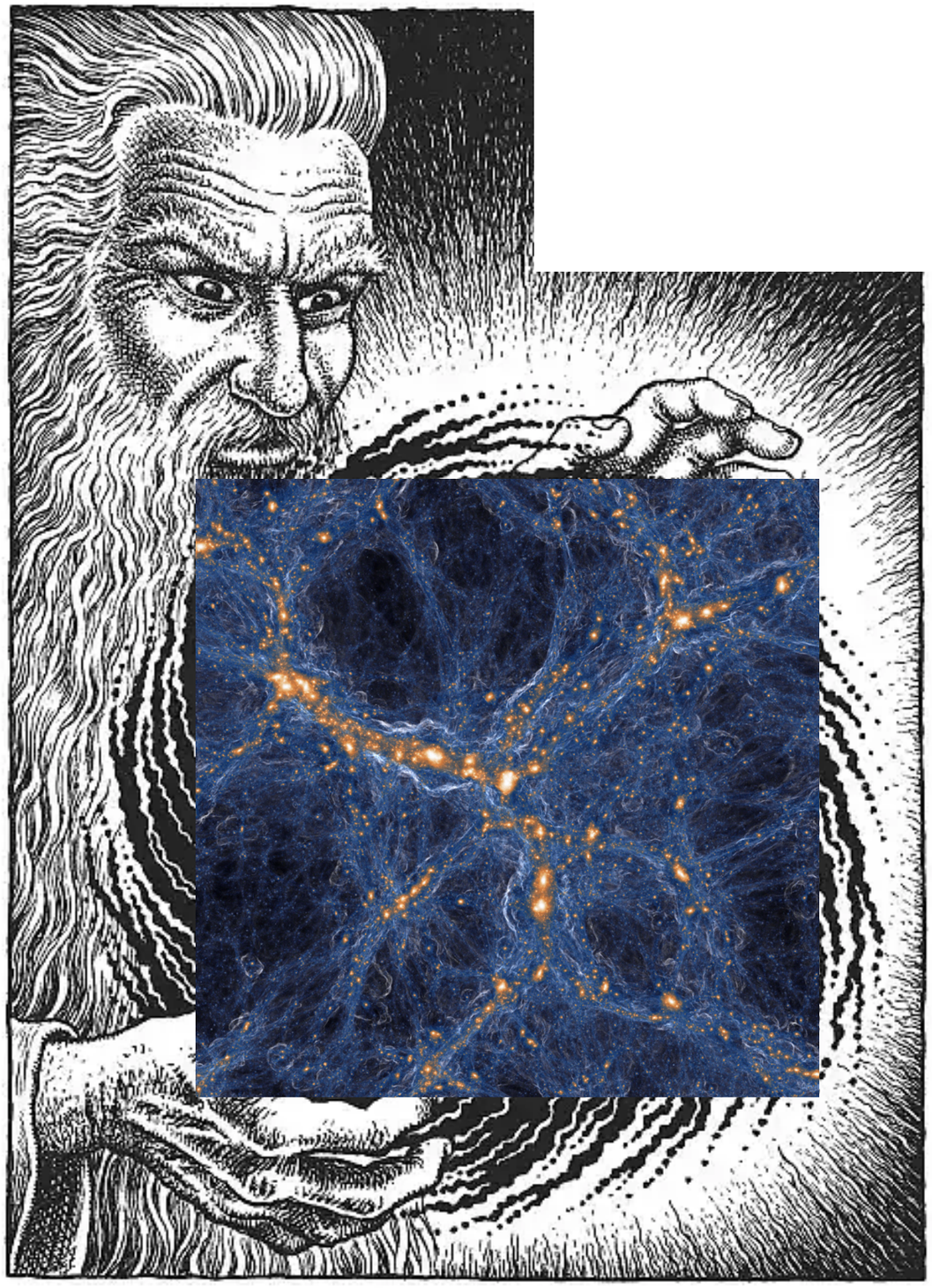
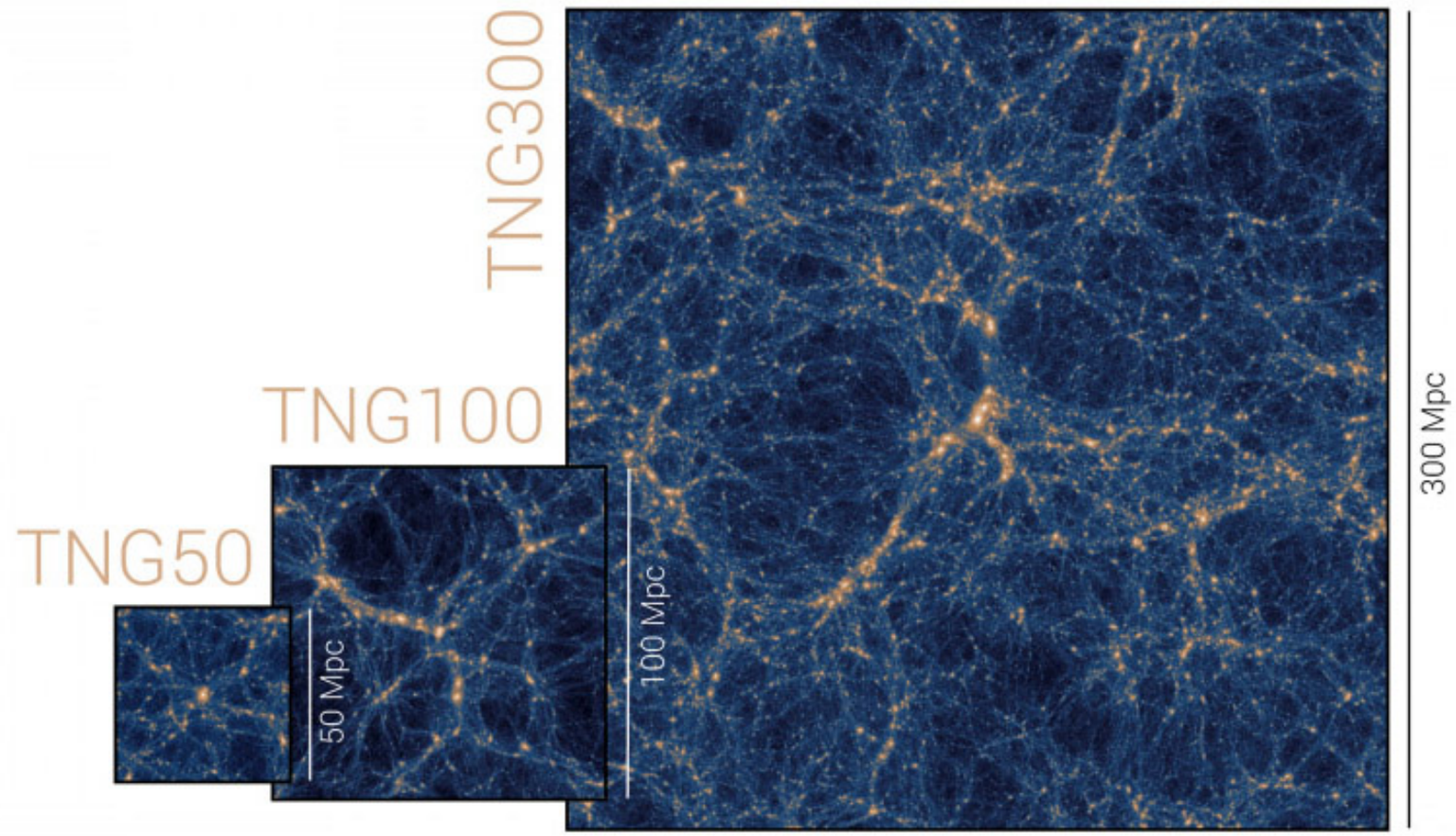


TNG50 simulations

- Part of the IllustrisTNG suite (Pillepich et al. 2019; Nelson et al. 2019a,b)



www.tng-project.com

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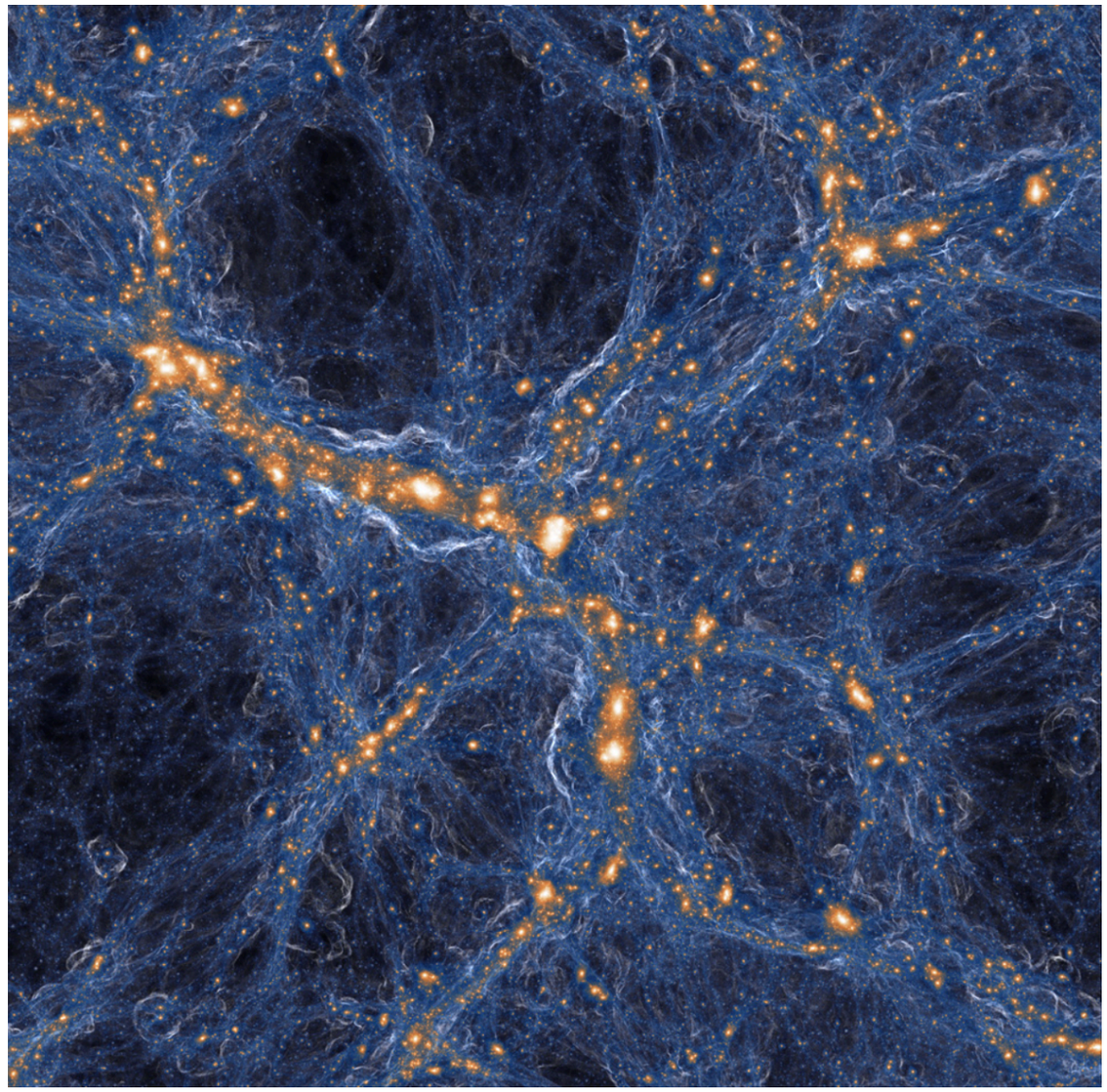

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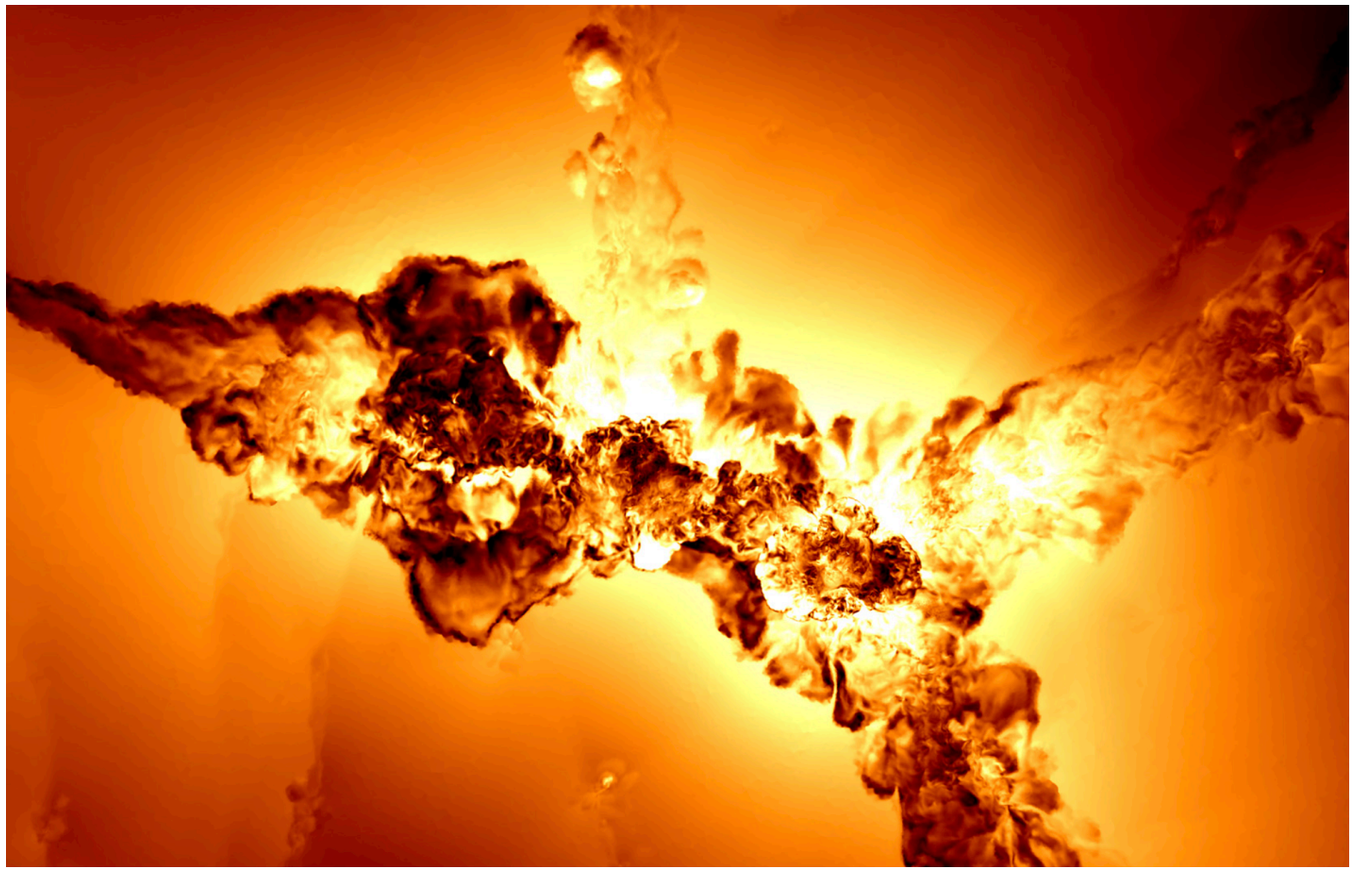

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- ΛCDM cosmology

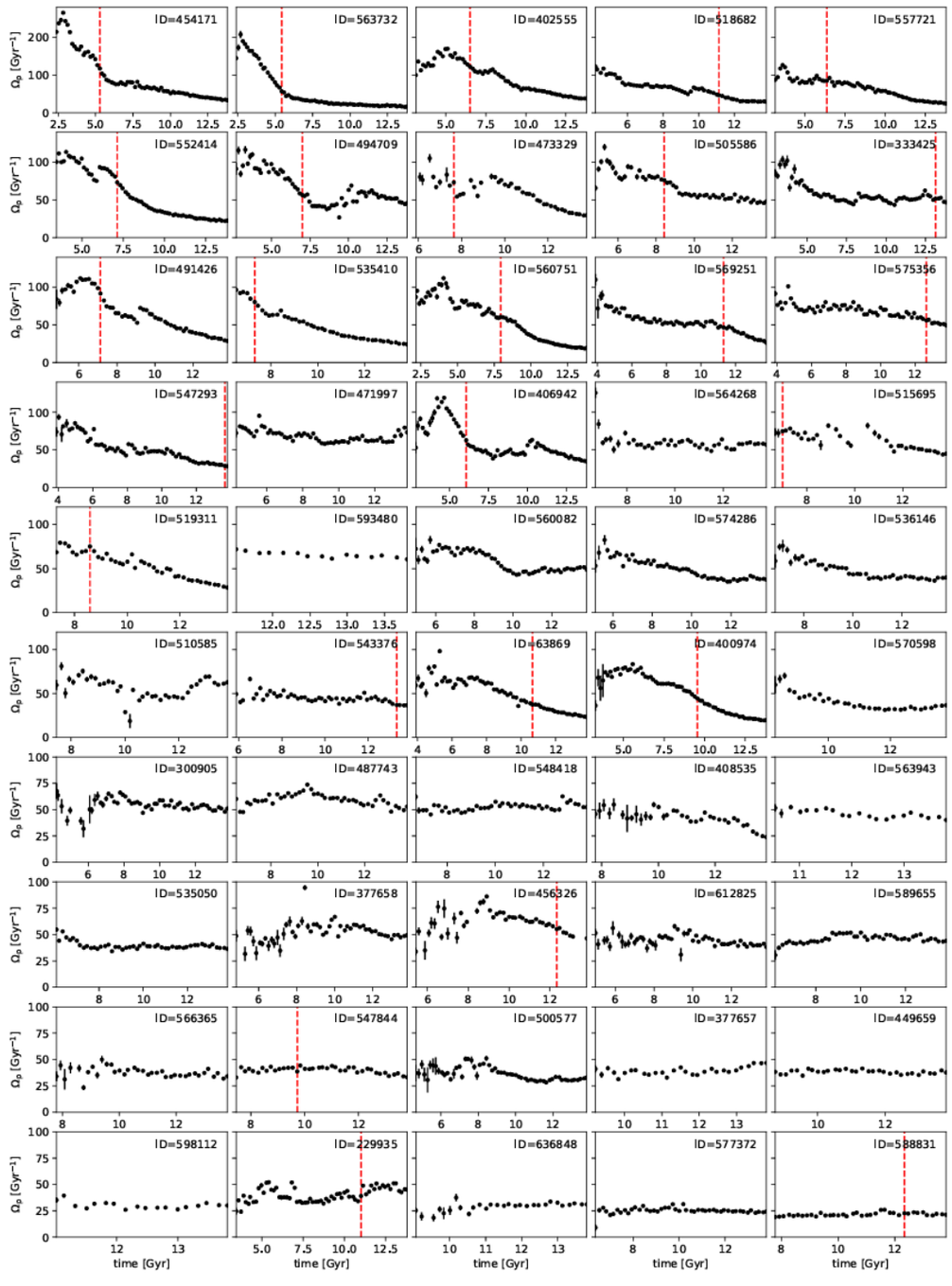
- Moving mesh hydro

- Subgrid model including: star formation, gas cooling, AGN & stellar feedback, magnetic fields …

www.tng-project.com

Pattern speed evolution of bars in TNG50

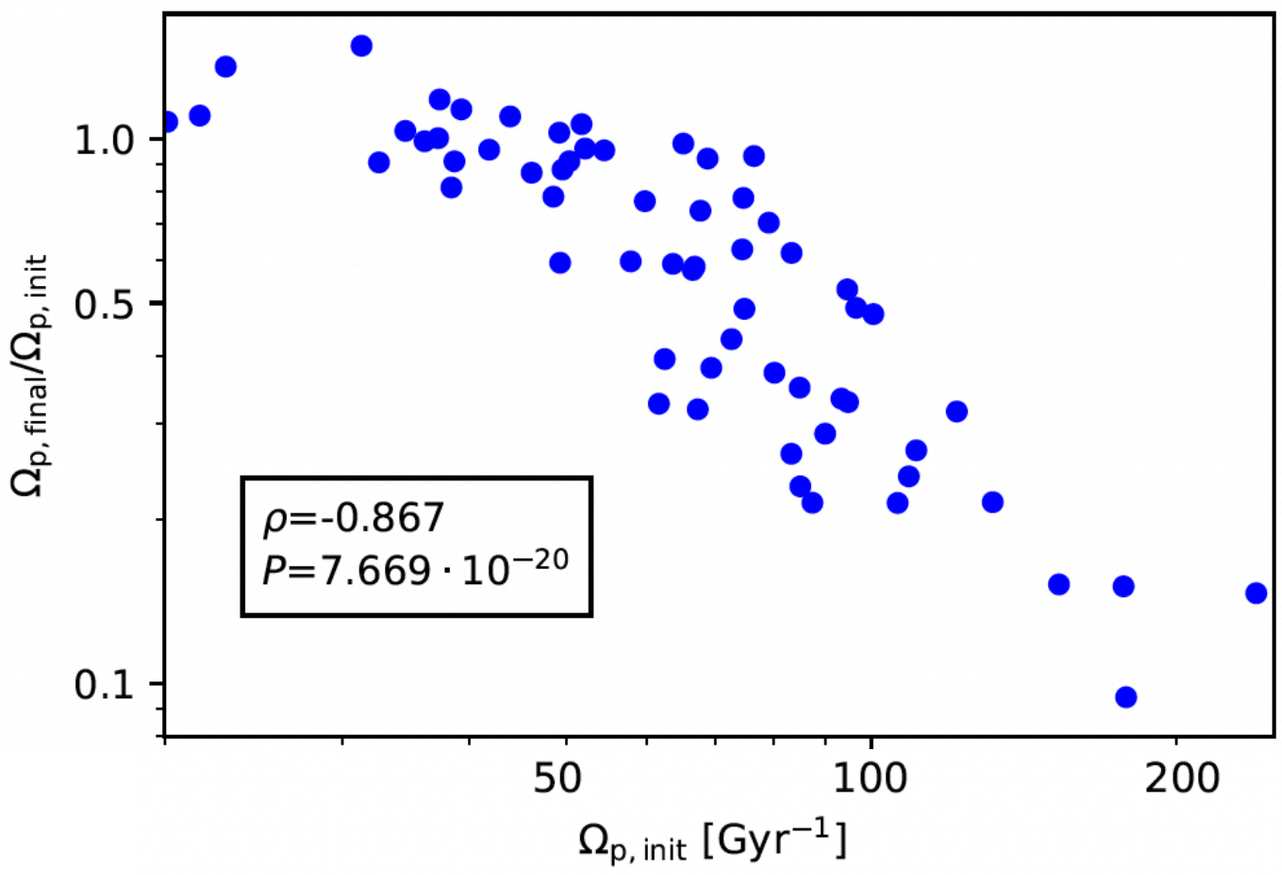
- N=62 barred galaxies
- Measurements with the recent code `patternSpeed.py` (Dehnen, Semczuk & Schönrich 2023)



Semczuk et al. (2024)

Takeaway points

- Bars that start at high Ω_p slow down more
- Maximum circular velocity scales the initial Ω_p



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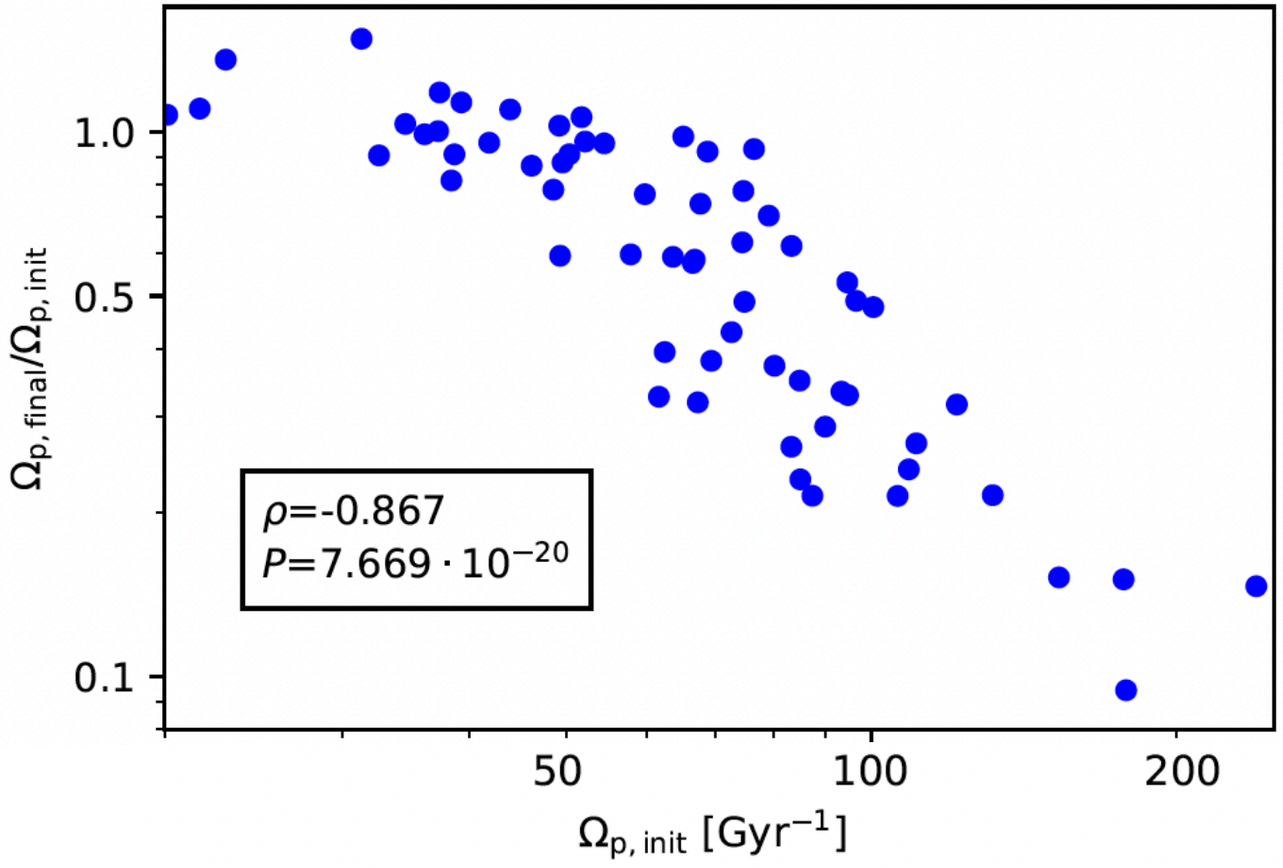

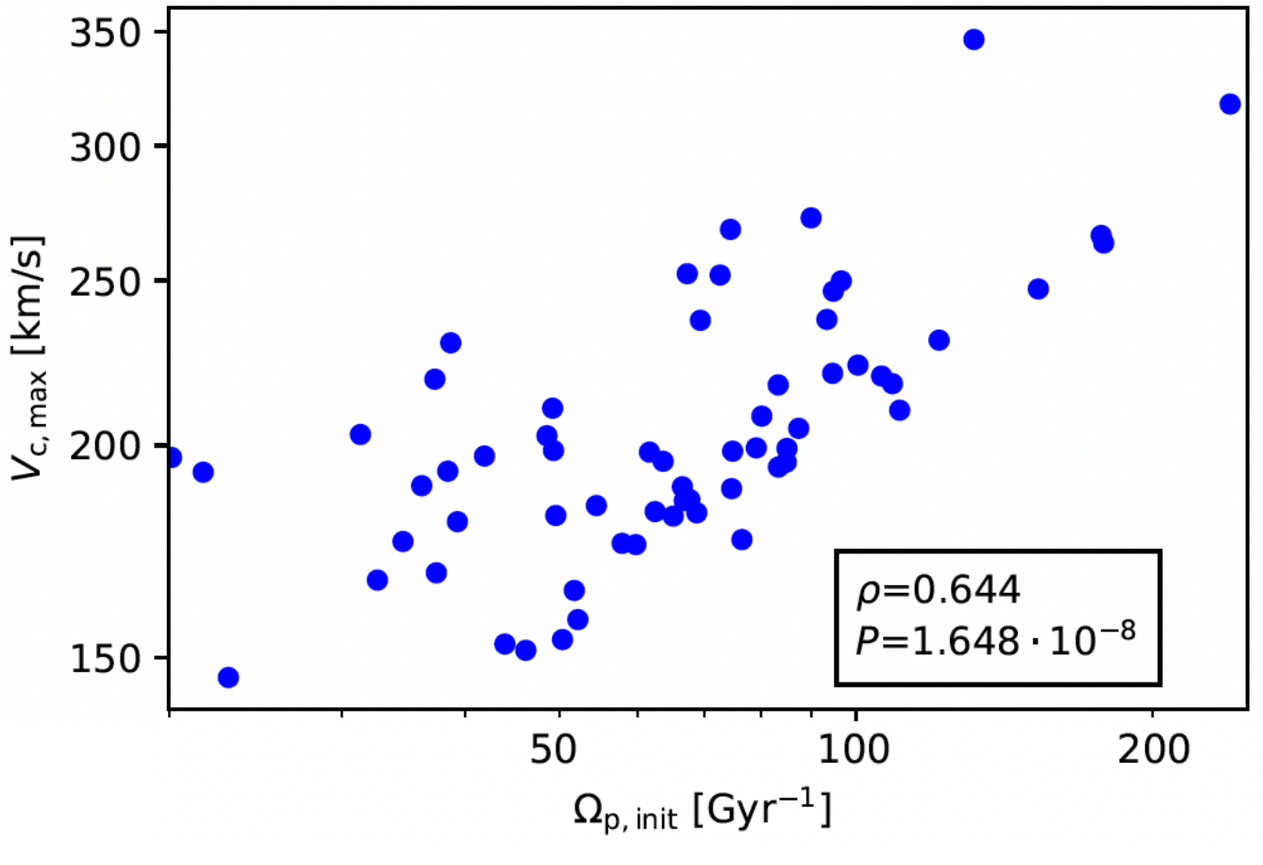

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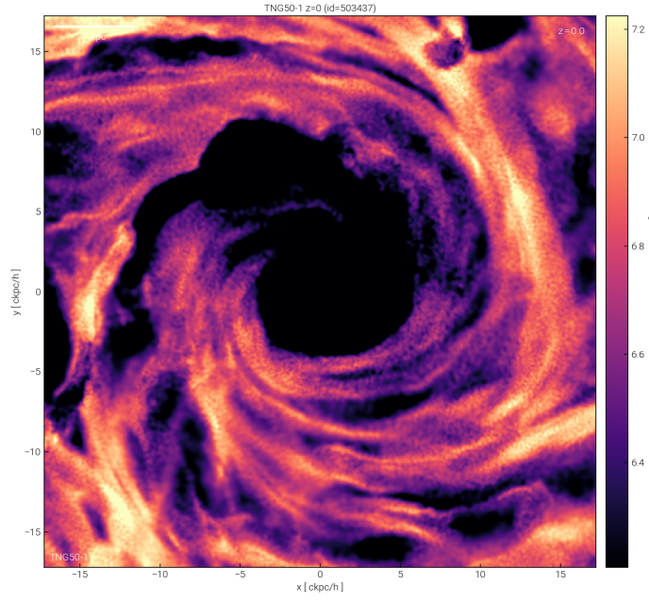

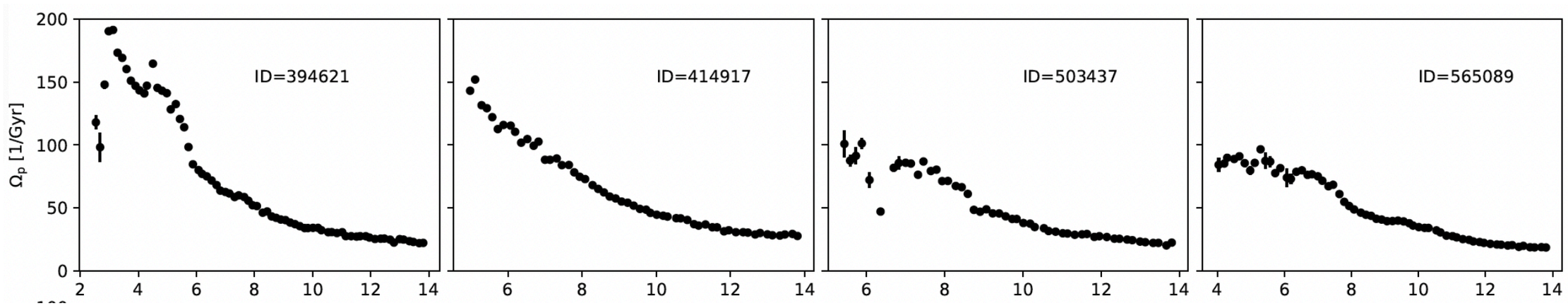

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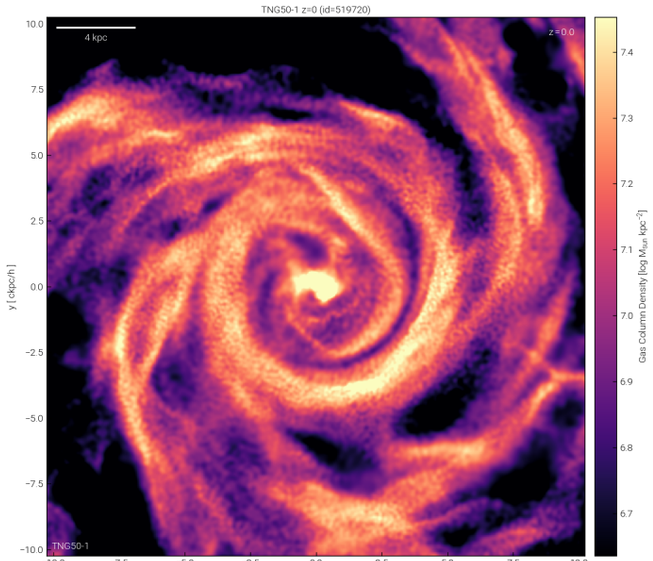
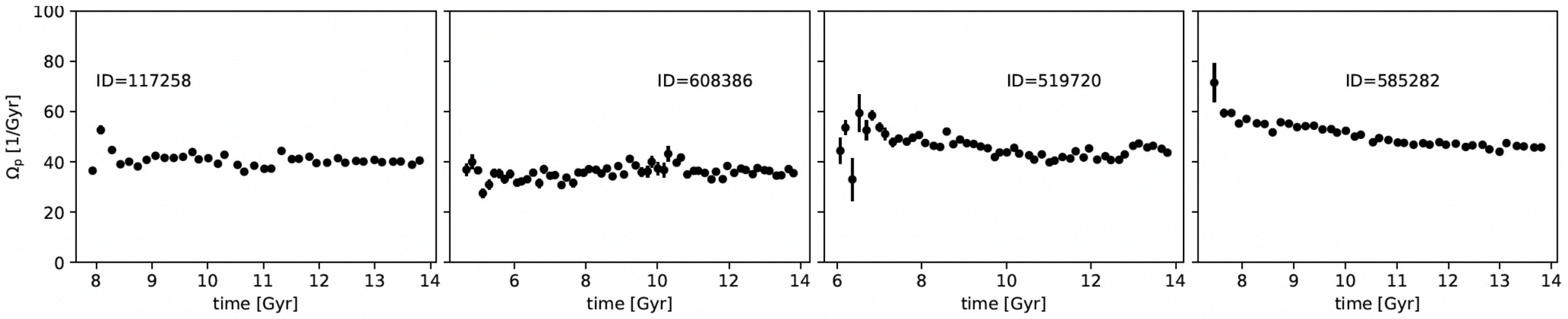
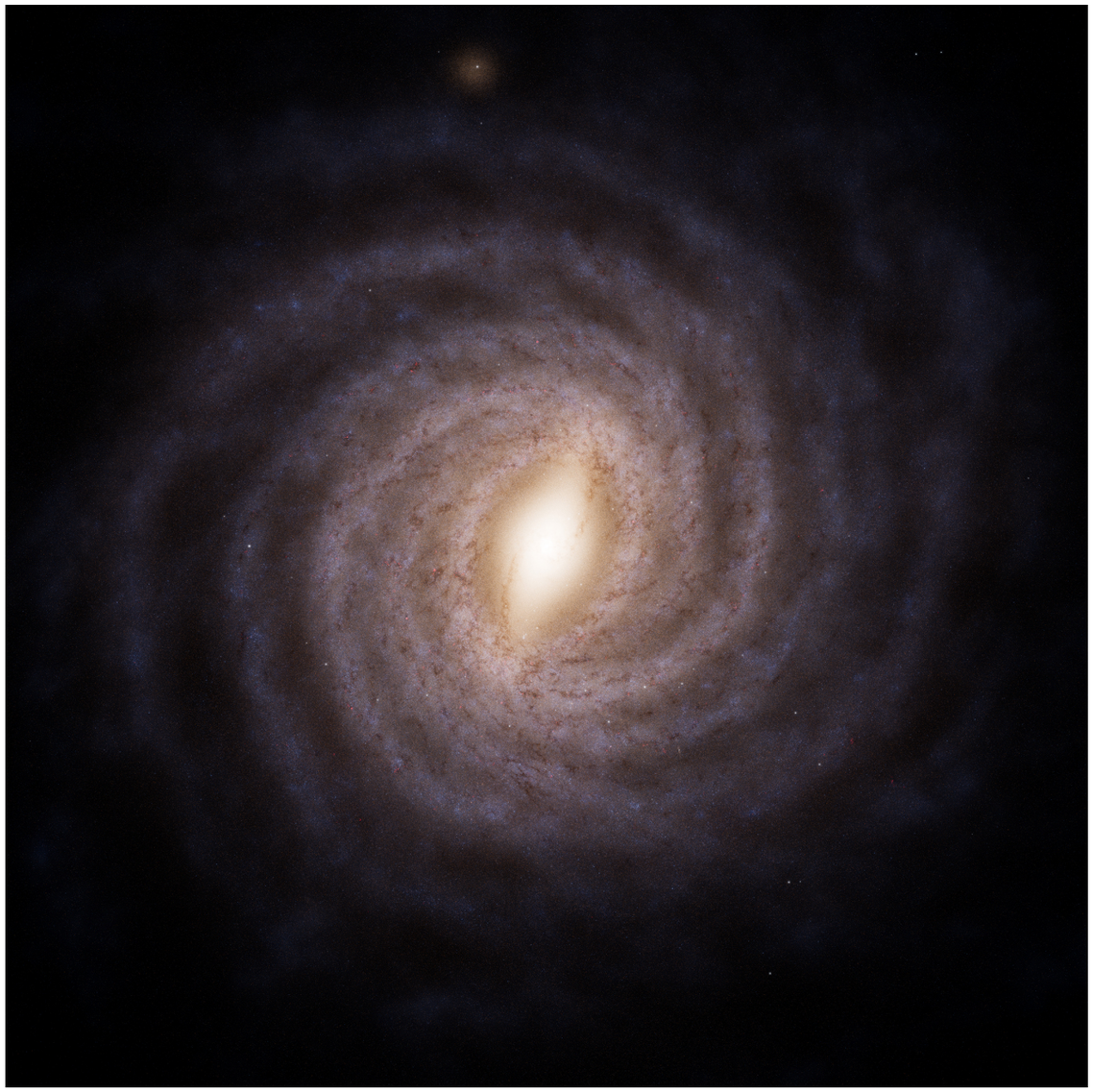
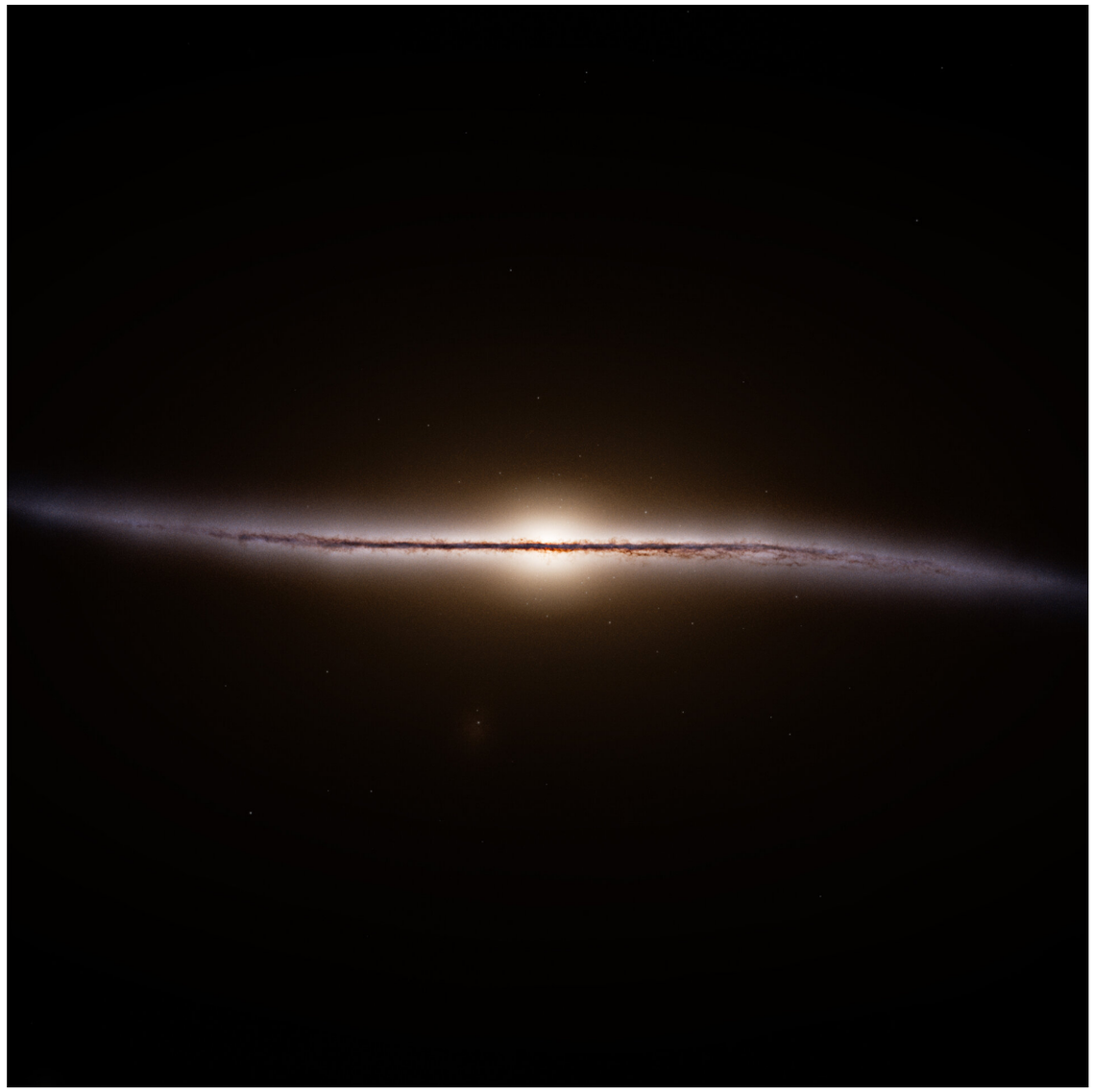




Semczuk et al. (2024)

Back to the Milky Way





Most recent artist's impression of the Milky Way (credit: ESA/Gaia/DPAC, Stefan Payne-Wardenaar CC BY-SA 3.0 IGO or ESA standard License)

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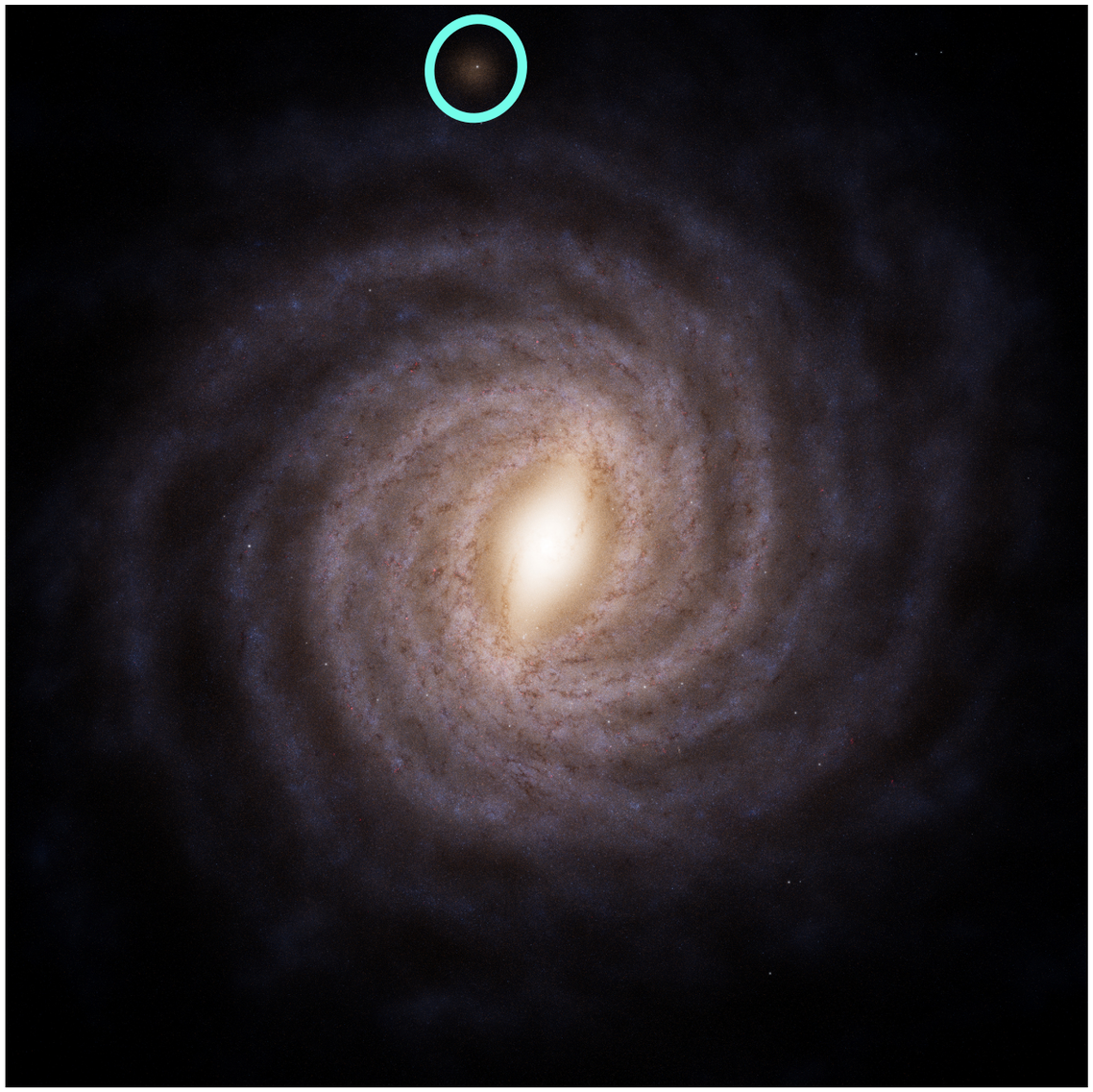

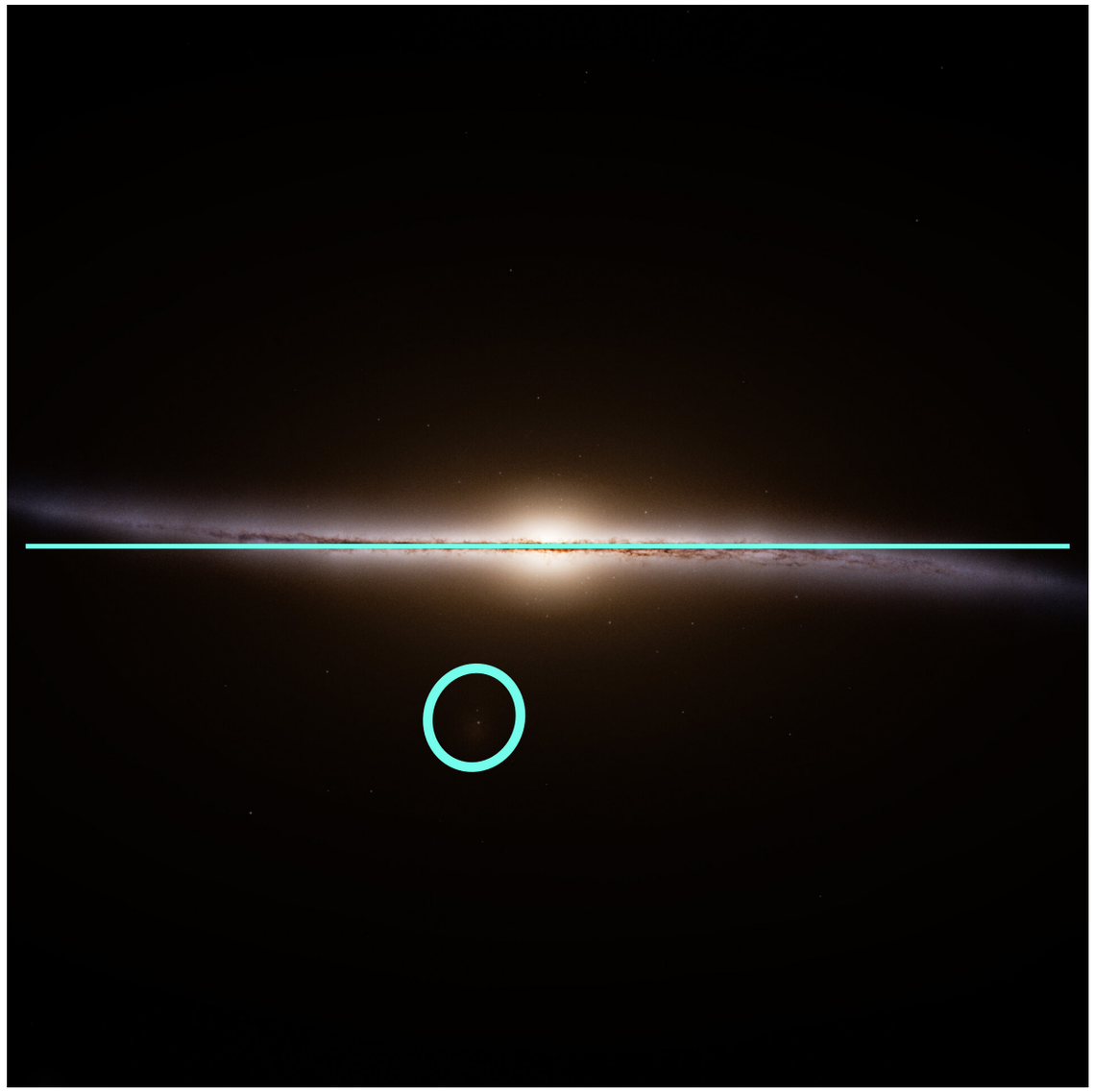

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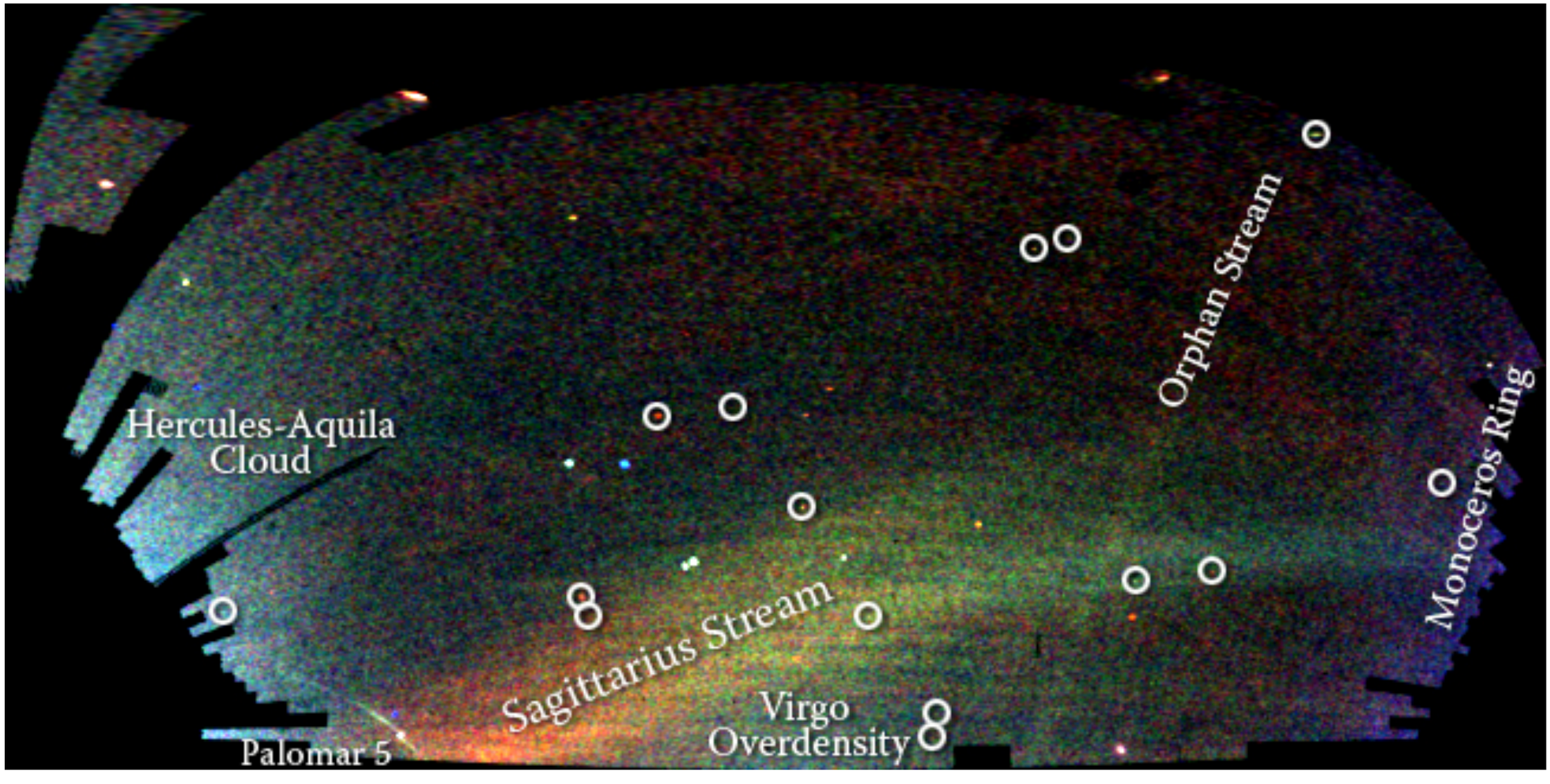
Sagittarius dwarf galaxy

- Discovered as a progenitor of the Sagittarius stream by Ibata et al. (1994)



Credit: V. Belokurov/SDSS

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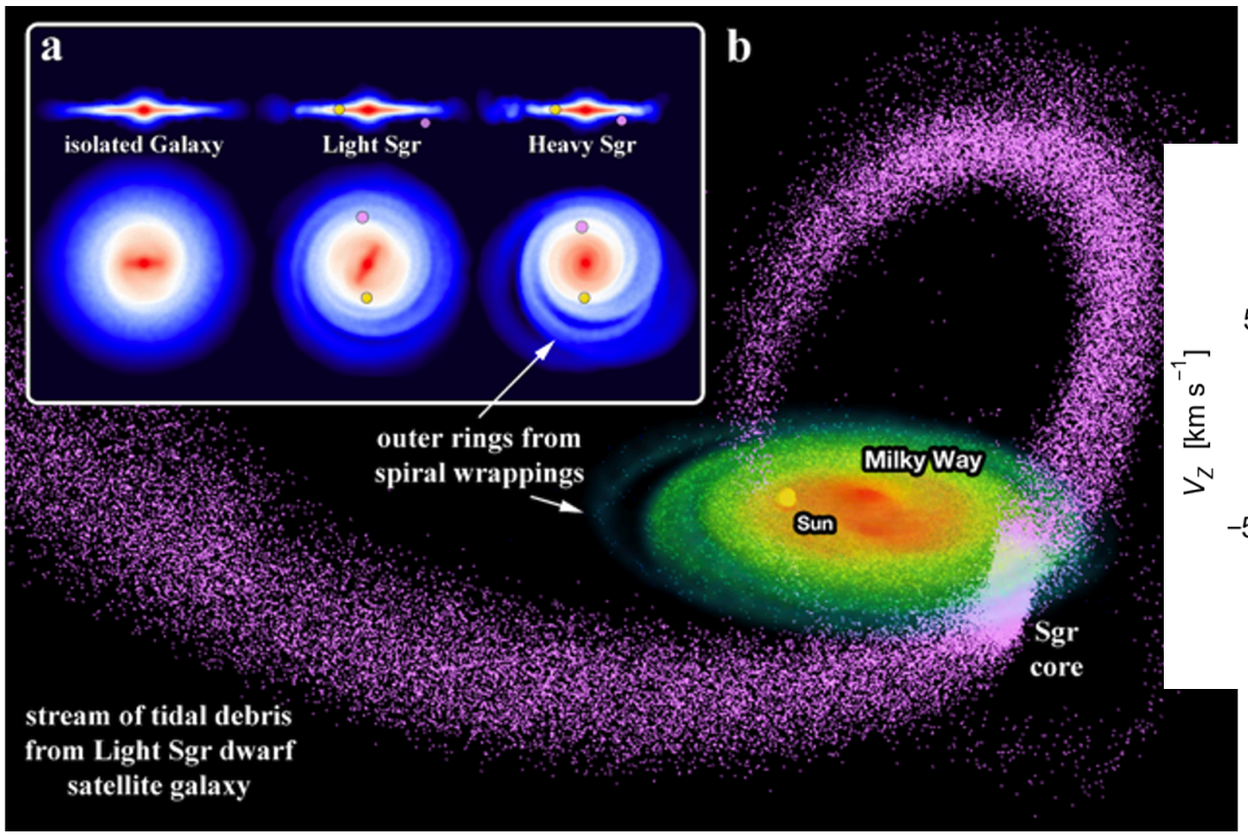
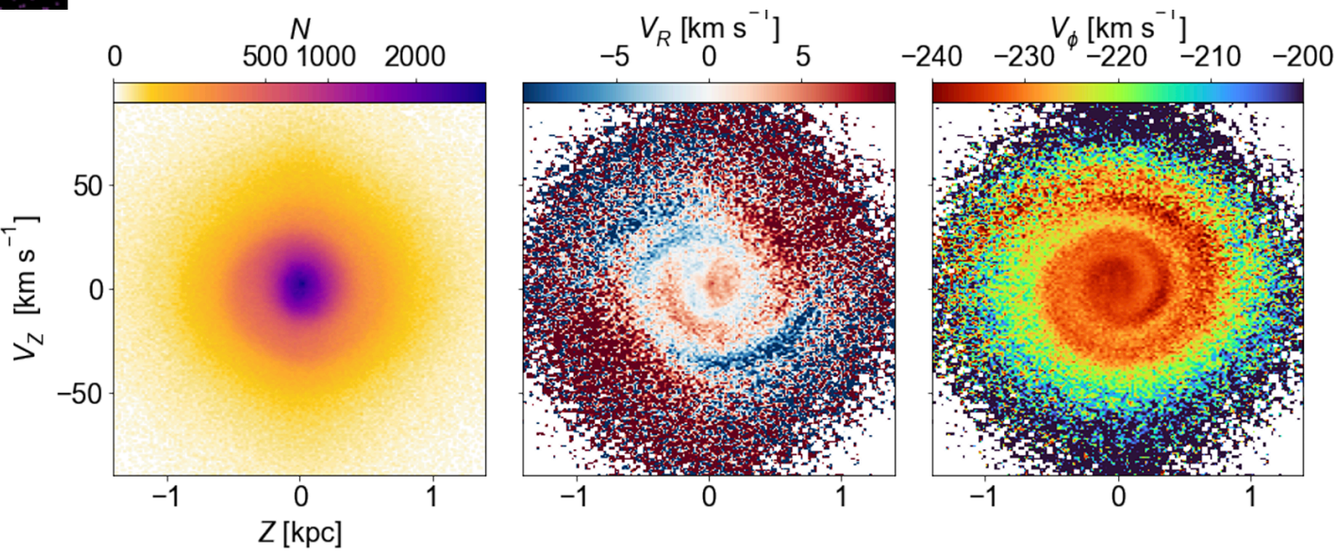
- Hypothesised to perturb the Milky Way disc (warp, spiral arms, corrugation, Gaia phase spiral, star formation episodes …)



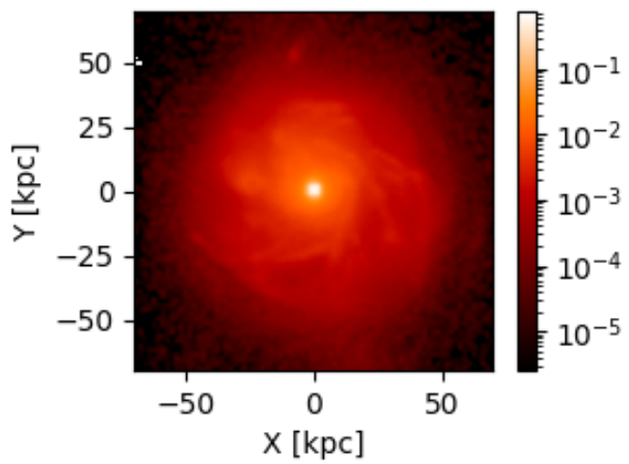
Purcell et al. (2011)

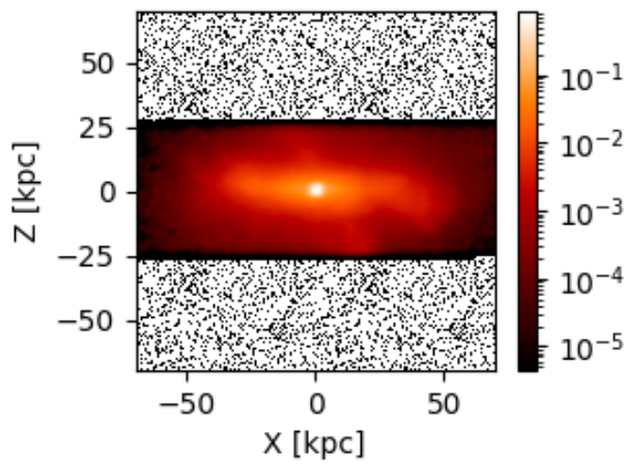


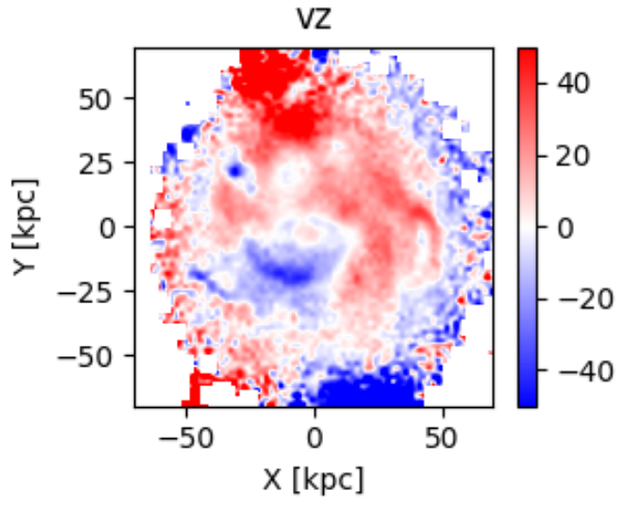
Antoja et al. (2018; 2023)

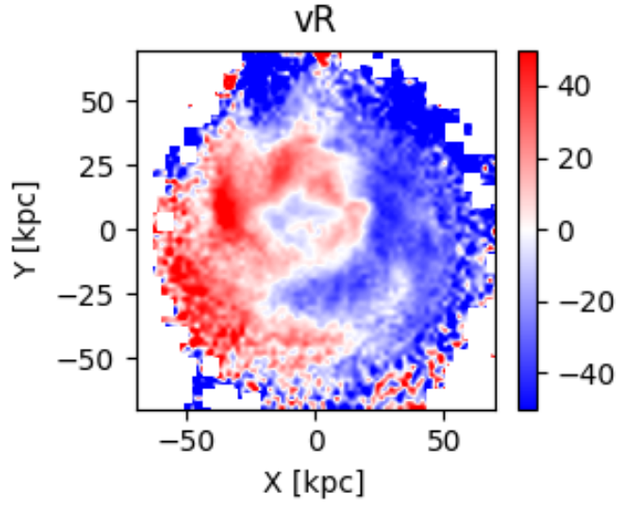
Sagittarius-like interactions in TNG50

- Most work on Sag-MW interactions were done using the classical near-equilibrium tools
- Goal: check how cosmologically evolved discs react to Sag-like perturbations





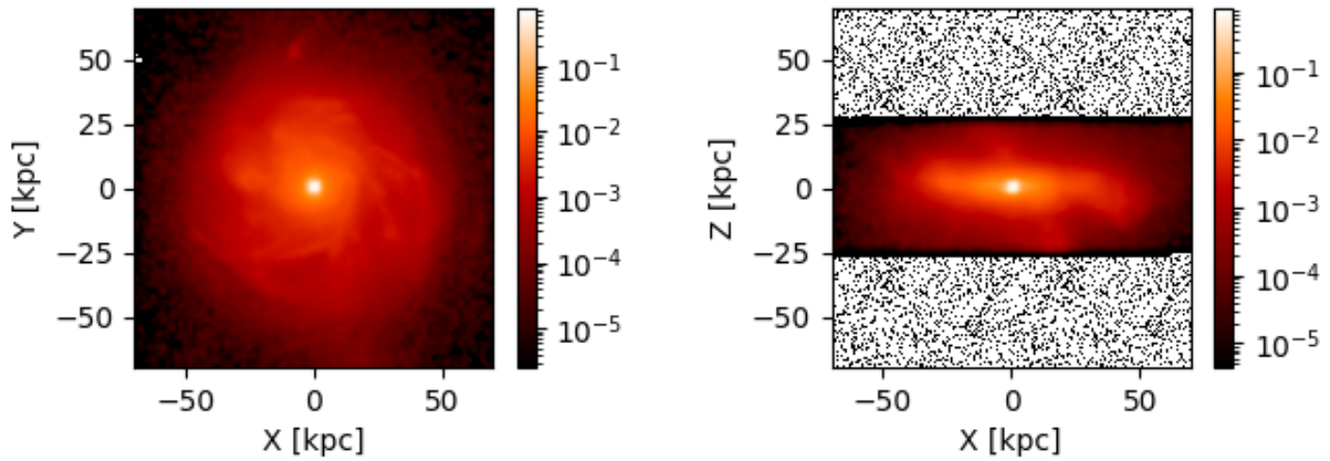


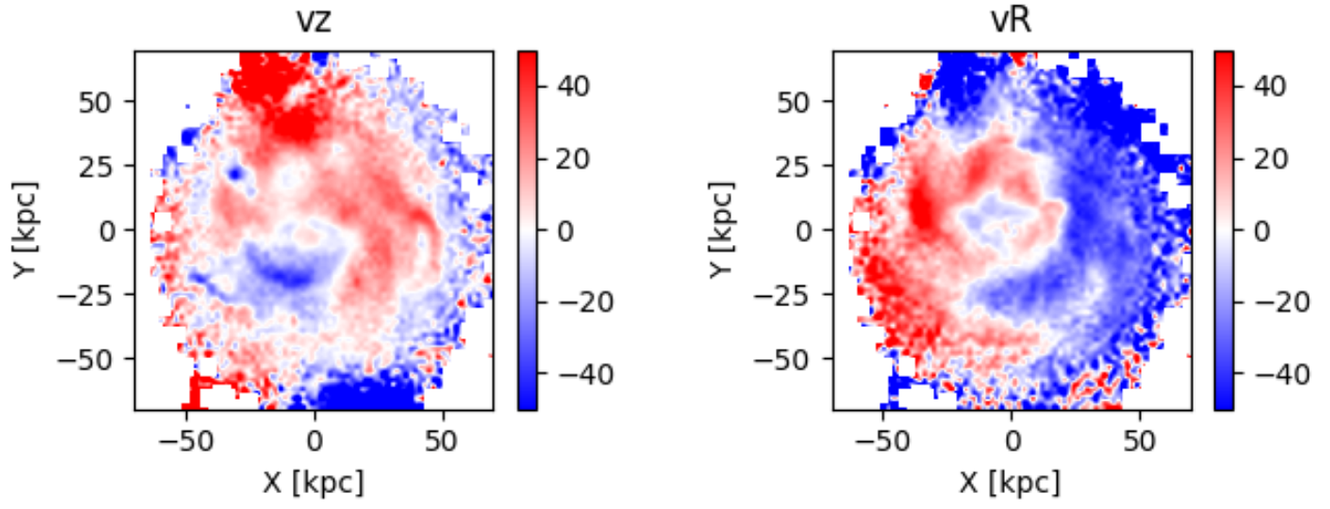


Semczuk et al., in prep

Sagittarius-like interactions in TNG50

- Morphology and kinematics are often affected
- Little effect on the star formation rates





Semczuk et al., in prep

Summary

- Gaia allows us to study dynamics of the Milky Way under an extremely good "microscope"
- We learn more details on phenomena like bar slowdown and vertical perturbations of discs
- Models, theory, simulations have a lot of catching up to fully grasp these phenomena