Title: The Kinematics of the Hot and X-ray Emitting Circumgalactic Medium: Predictions from Simulations

Speakers: John ZuHone

Collection/Series: Cosmic Ecosystems

Subject: Cosmology

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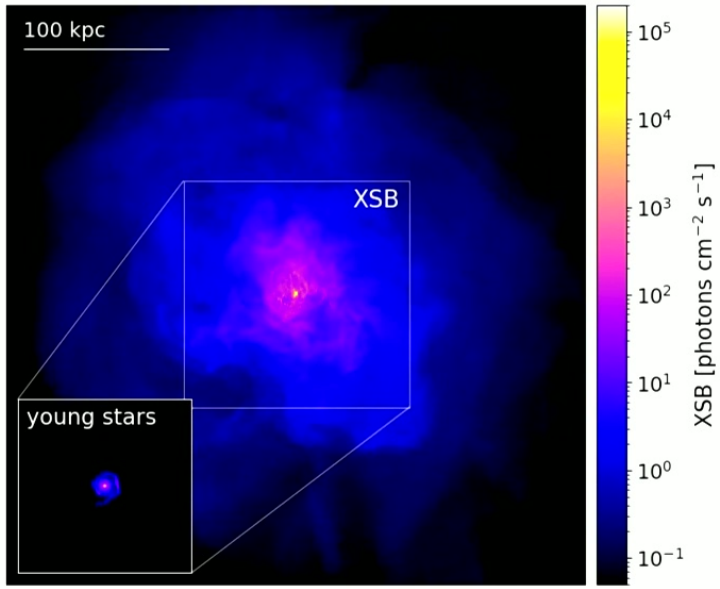
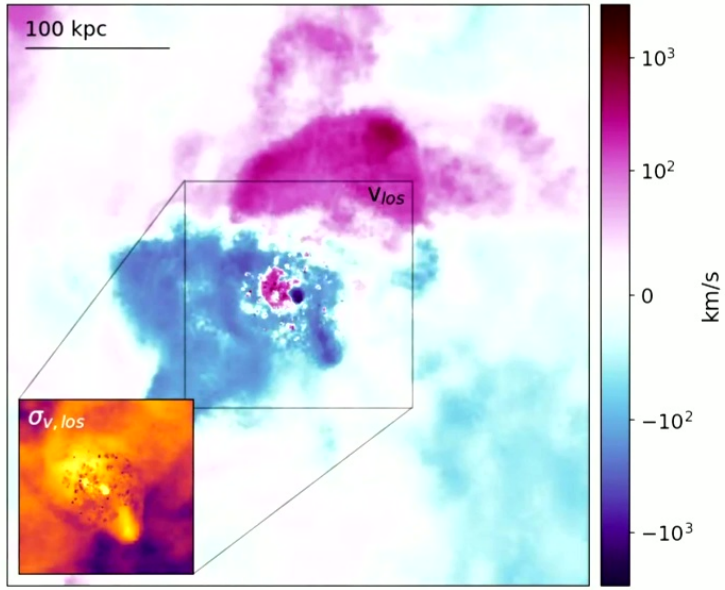
Abstract:

In massive galaxies a significant fraction by mass of the circumgalactic medium is expected to be in the hot, X-ray emitting phase. Little is known about this gas since it is faint and is outshone by the Milky Way's own hot circumgalactic medium, and X-ray observatories with CCDs are unable to distinguish the emission lines of the former from the latter. Future observatories with X-ray IFUs would be able to measure key emission lines of the hot CGM, and use them to map the velocity structure of this phase. In this talk, I will show predictions from galaxies from a range of cosmological simulations for the velocity field of the hot CGM, showing signatures of rotation, inflows, and outflows from AGN and SNe feedback. Crucially, the velocity structure depends on the feedback model used, so that future observations may be used to constrain models used in cosmological simulations.

The Kinematics of the Hot and X-ray Emitting Circumgalactic Medium: Predictions from Simulations





John ZuHone with Emily Silich, Gerrit Schellenberger, Cameron Hummels, Anna Ogorzałek, Ben Oppenheimer, and many others…

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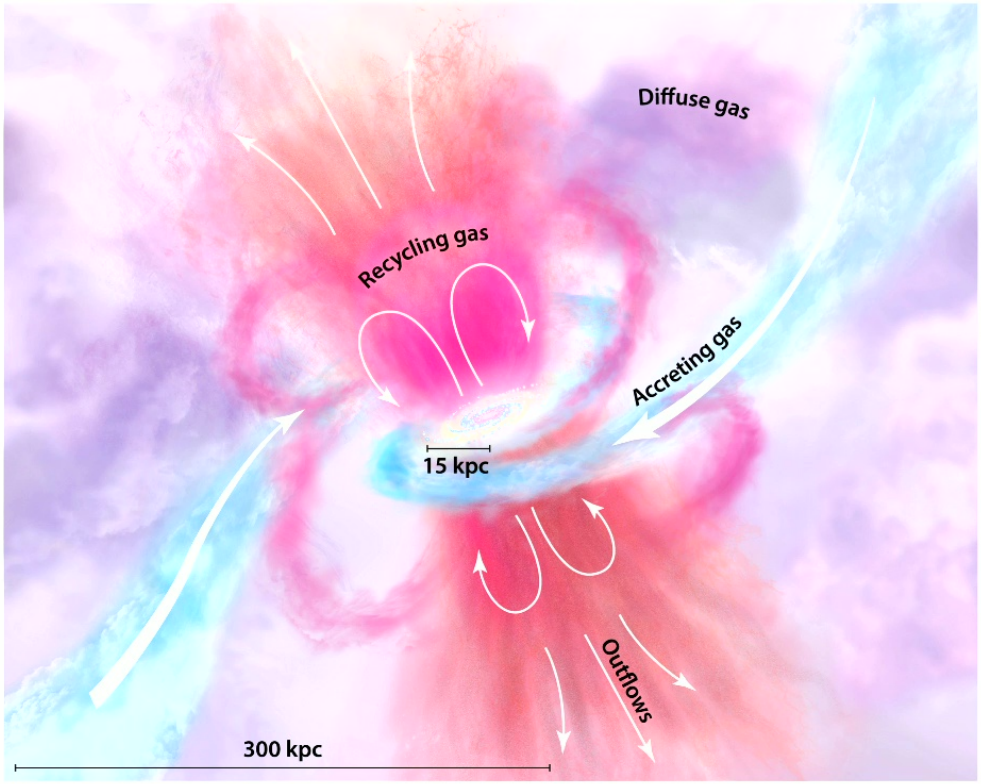
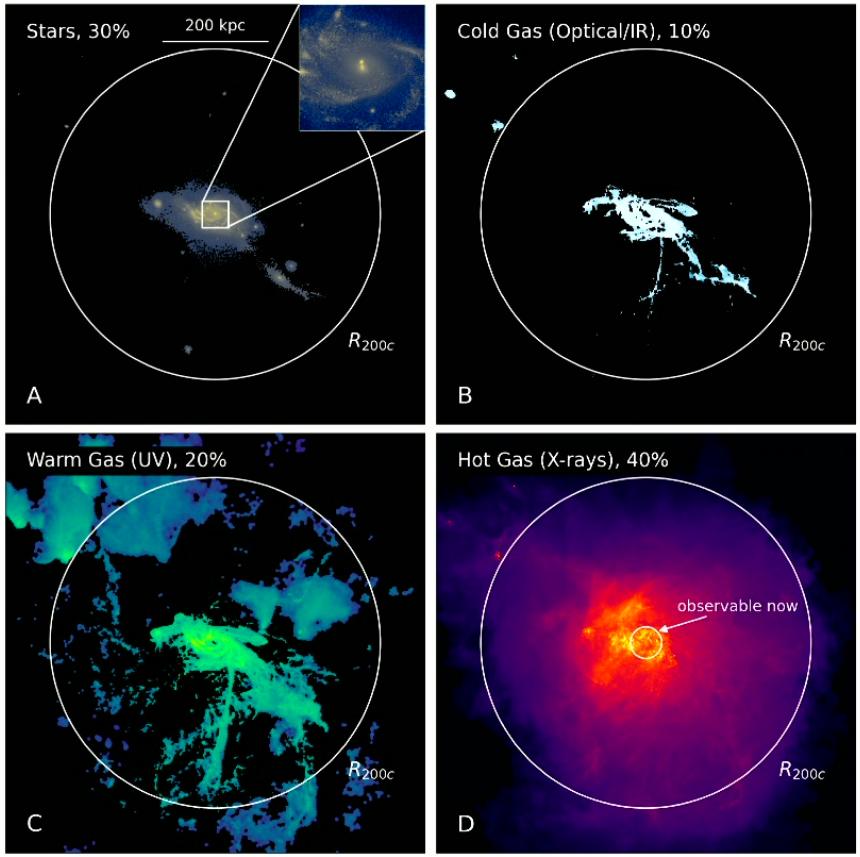
The Phases of the Circumgalactic Medium



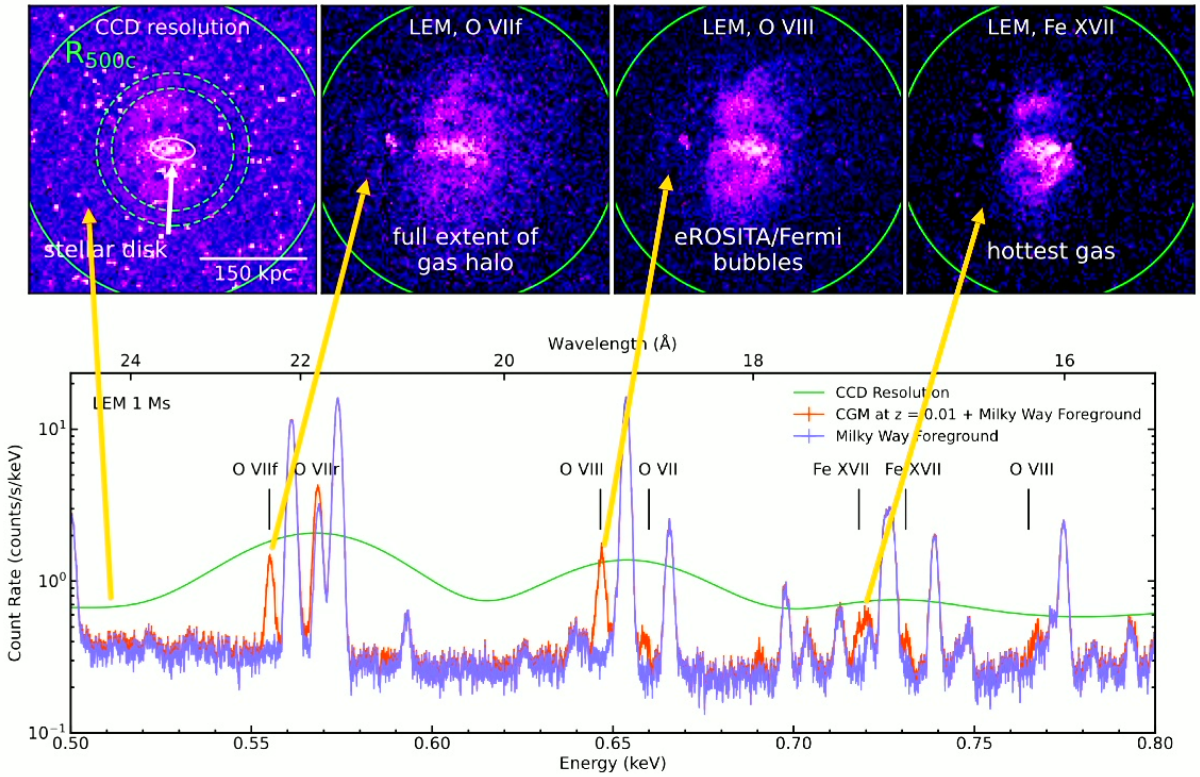
Tumlinson et al. (2017)



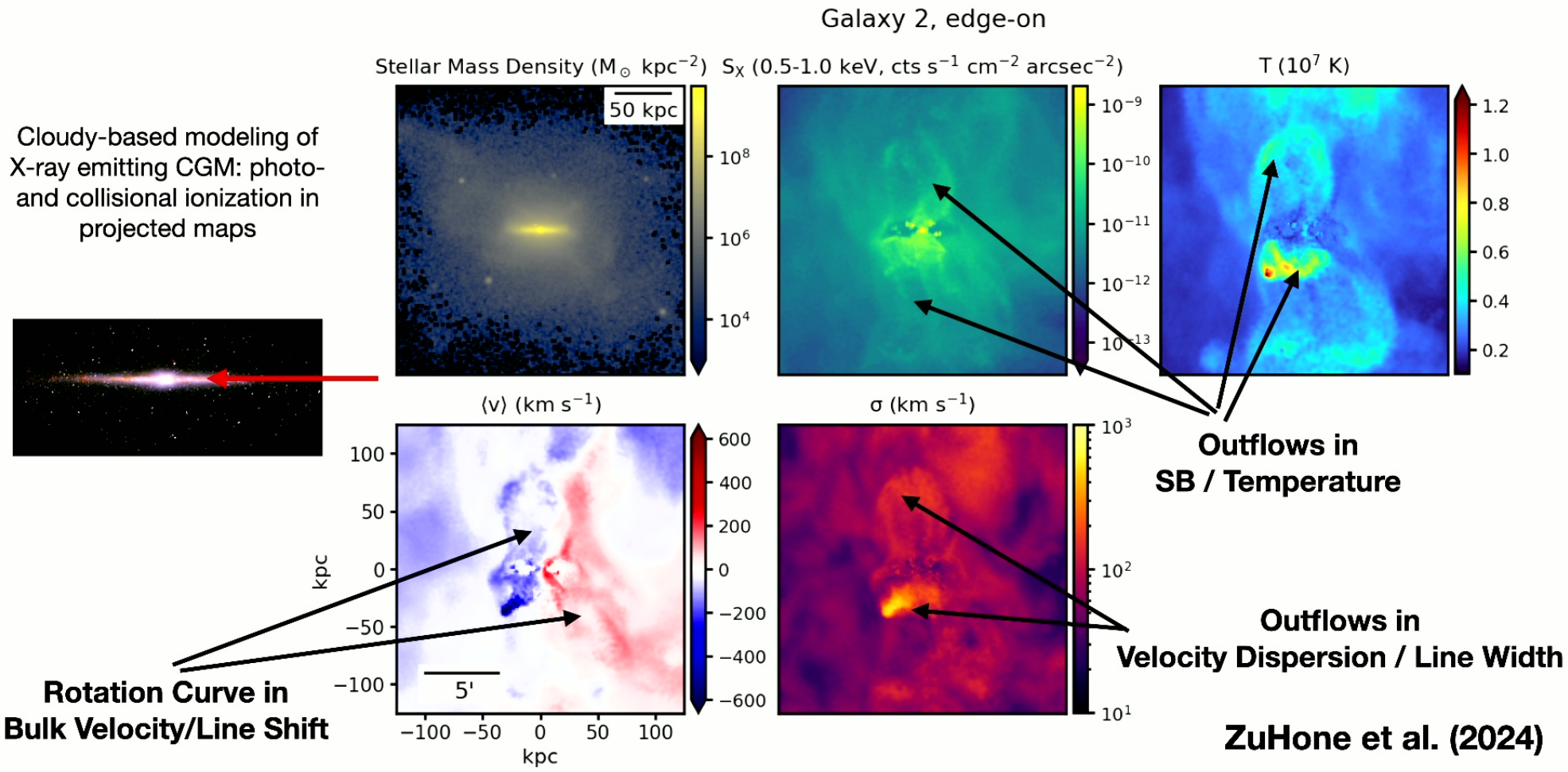
A ~MW-mass galaxy from TNG50

How Do We Observe the Hot CGM?

- The main problem is that we happen to be sitting inside of a MW-mass galaxy with a hot CGM
- CCD-based observations (Chandra, XMM-Newton, eROSITA) can observe it in emission in bright/nearby sources (Sanskriti Das' talk from earlier today), or from stacking
- Can also be detected using the SZ effect, or with X-ray absorption line studies (Sanskriti Das' talk again)
- In order to observe the hot CGM in distinct emission lines for more distant galaxies, one needs an X-ray microcalorimeter like XRISM, but with soft band sensitivity—e.g. Athena/XIFU, Lynx, LEM

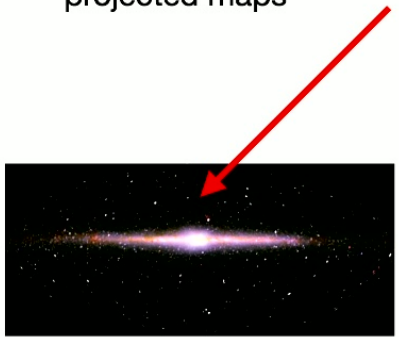


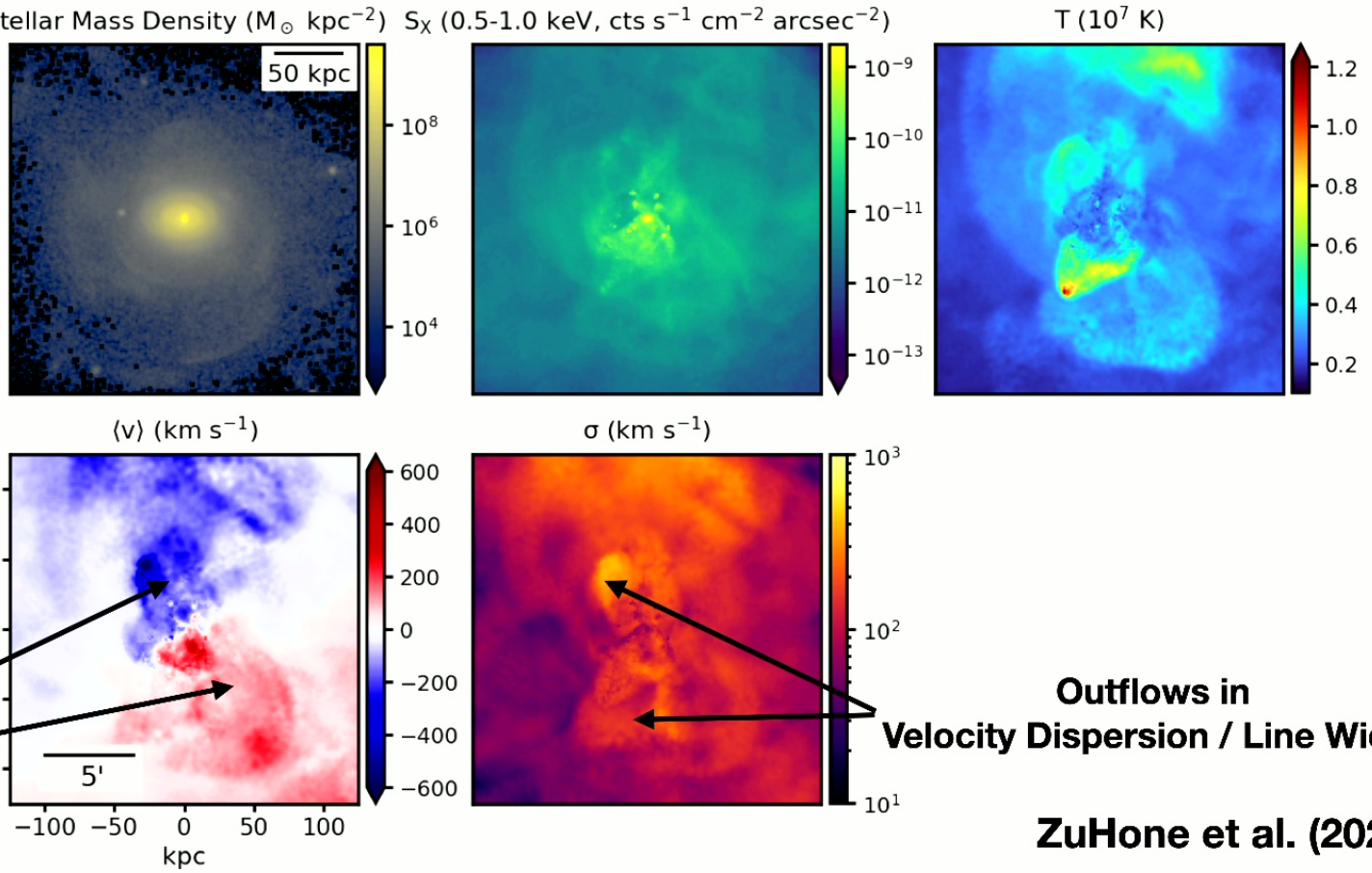
A ~MW-mass galaxy from TNG50: Edge-On



A ~MW-mass galaxy from TNG50: Mid-On

Cloudy-based modeling of X-ray emitting CGM: photo- and collisional ionization in projected maps



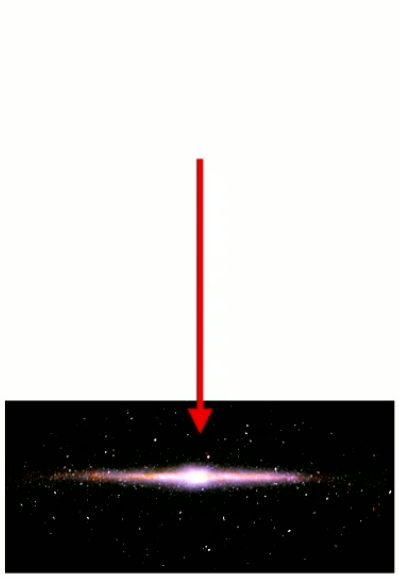


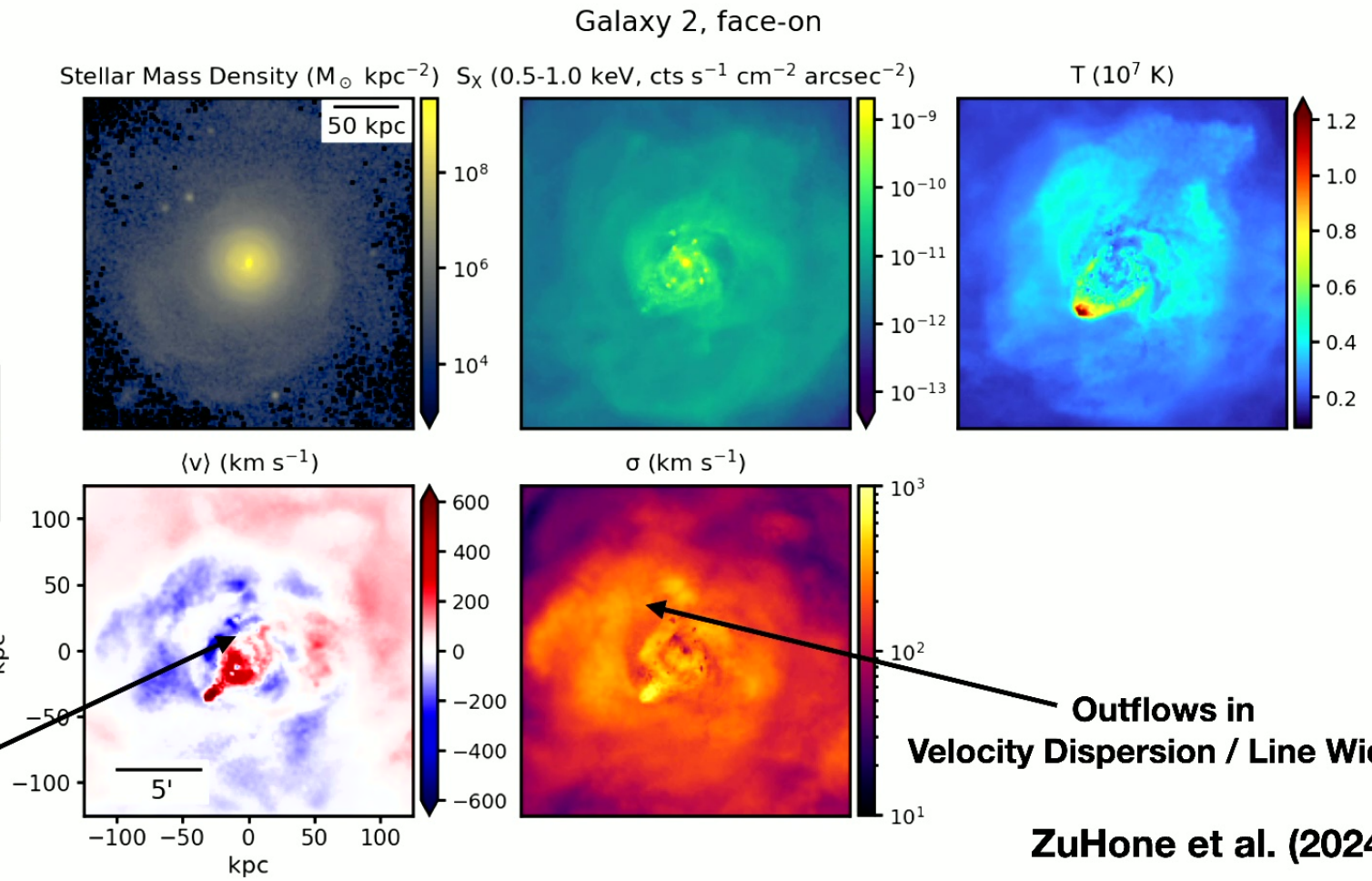
Rotation Curve and Outflows in Bulk Velocity/Line Shift

Outflows in Velocity Dispersion / Line Width

ZuHone et al. (2024)

A ~MW-mass galaxy from TNG50: Face-On





Cloudy-based modeling of X-ray emitting CGM: photo- and collisional ionization in projected maps

More turbulent-looking!

Outflows in Velocity Dispersion / Line Width

ZuHone et al. (2024)

Increasing the Sample

Emily Silich (Caltech)

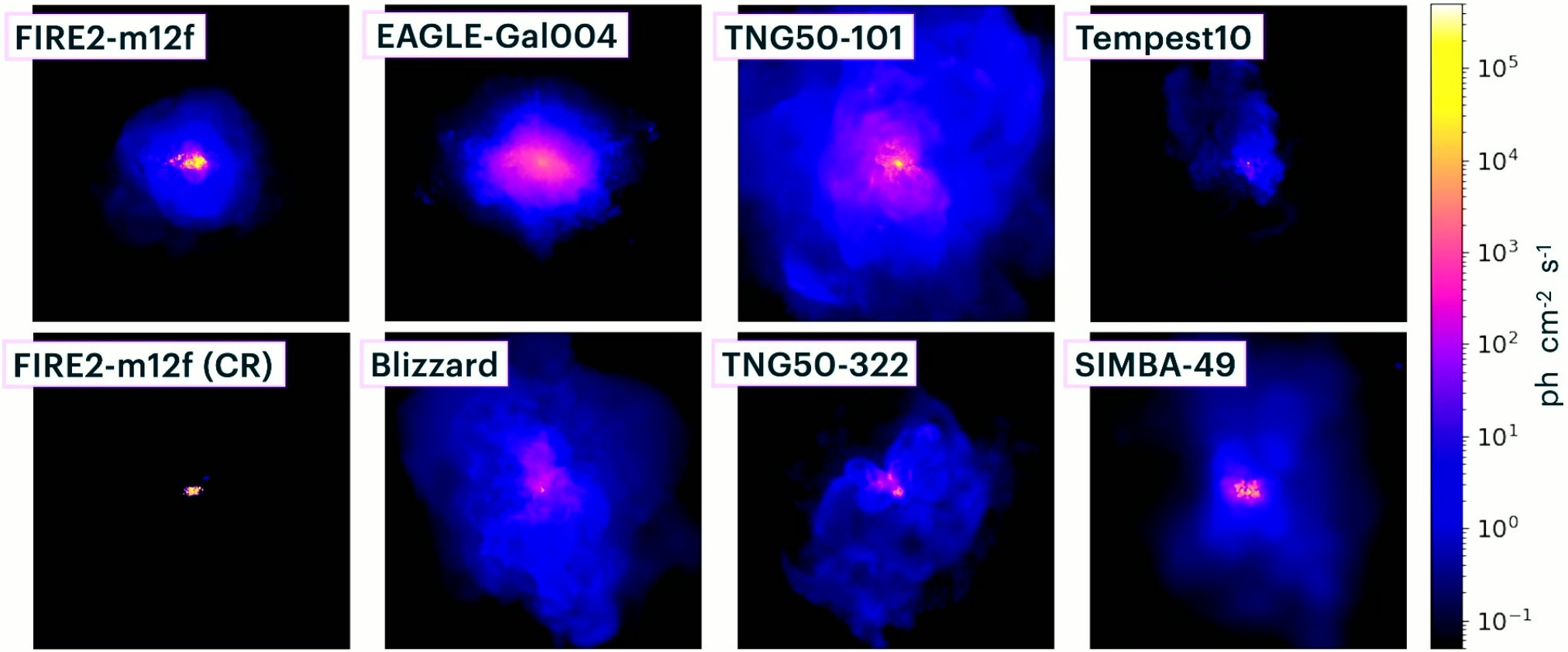
- Explore galaxies formed in a range of cosmological and/or zoom-in simulations
- Different codes, different resolutions
- Most importantly, different sources of feedback (stars vs. AGN) and different algorithms and models

Table 1. Overview of the cosmological hydrodynamical simulations analyzed in this study

Simulation	Run	Code	N_{gal}	Feedback physics	Reference(s)
Illustris-TNG	50	Arepo	8	stellar + AGN	Nelson et al. (2019); Pillepich et al. (2019)
FIRE2	fiducial	Gizmo	3	stellar	Hopkins et al. (2018)
FIRE2	CR-700	Gizmo	3	stellar + cosmic ray	Hopkins et al. (2020)
EAGLE	NEQ zooms	Gadget-3	5	stellar + AGN	Schaye et al. (2015); Oppenheimer et al. (2016)
FOGGIE	fiducial	Enzo	3	stellar	Peeples et al. (2019); Wright et al. (2024)
TEMPEST	10	Enzo	1	stellar	Hummels et al. (2019)
Simba	high-res	Gizmo	5	stellar + AGN	Davé et al. (2019)

Silich et al. (2025, arXiv:2506.17440)

X-ray Surface Brightness



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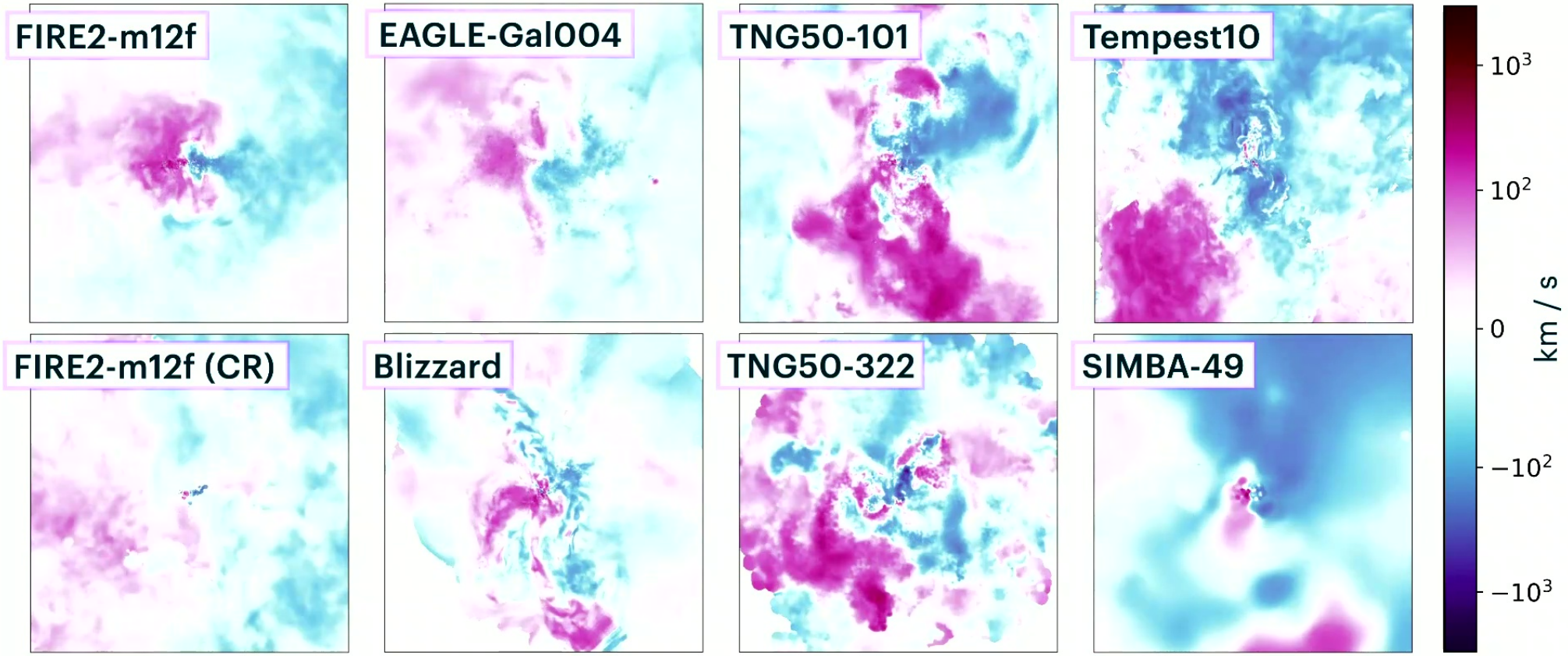
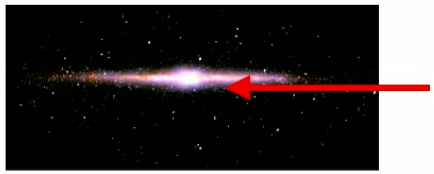
Bulk Velocity

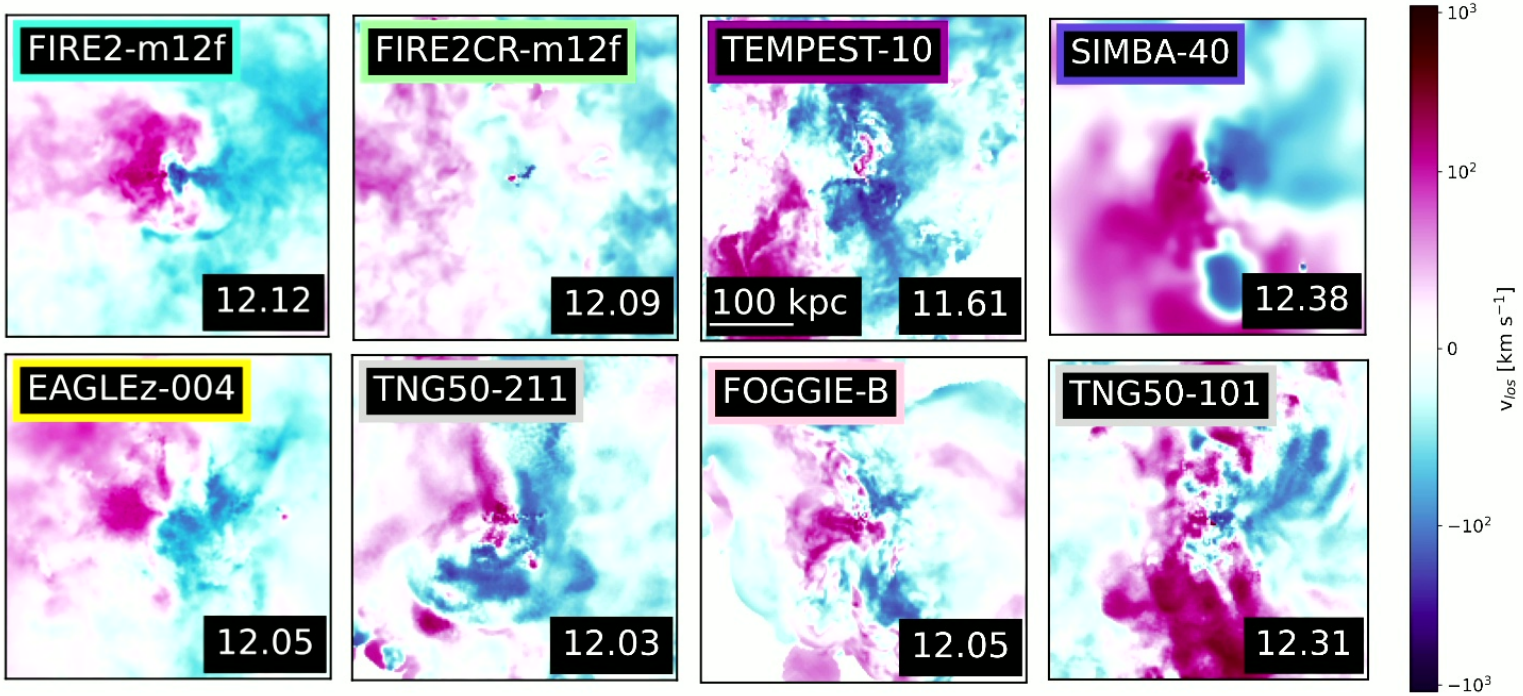


Silich et al. (2025, arXiv:2506.17440)

Bulk Velocity: Edge-On

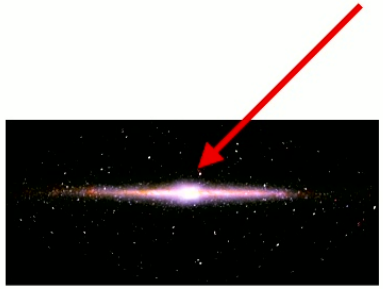


Evidence of rotation and turbulence

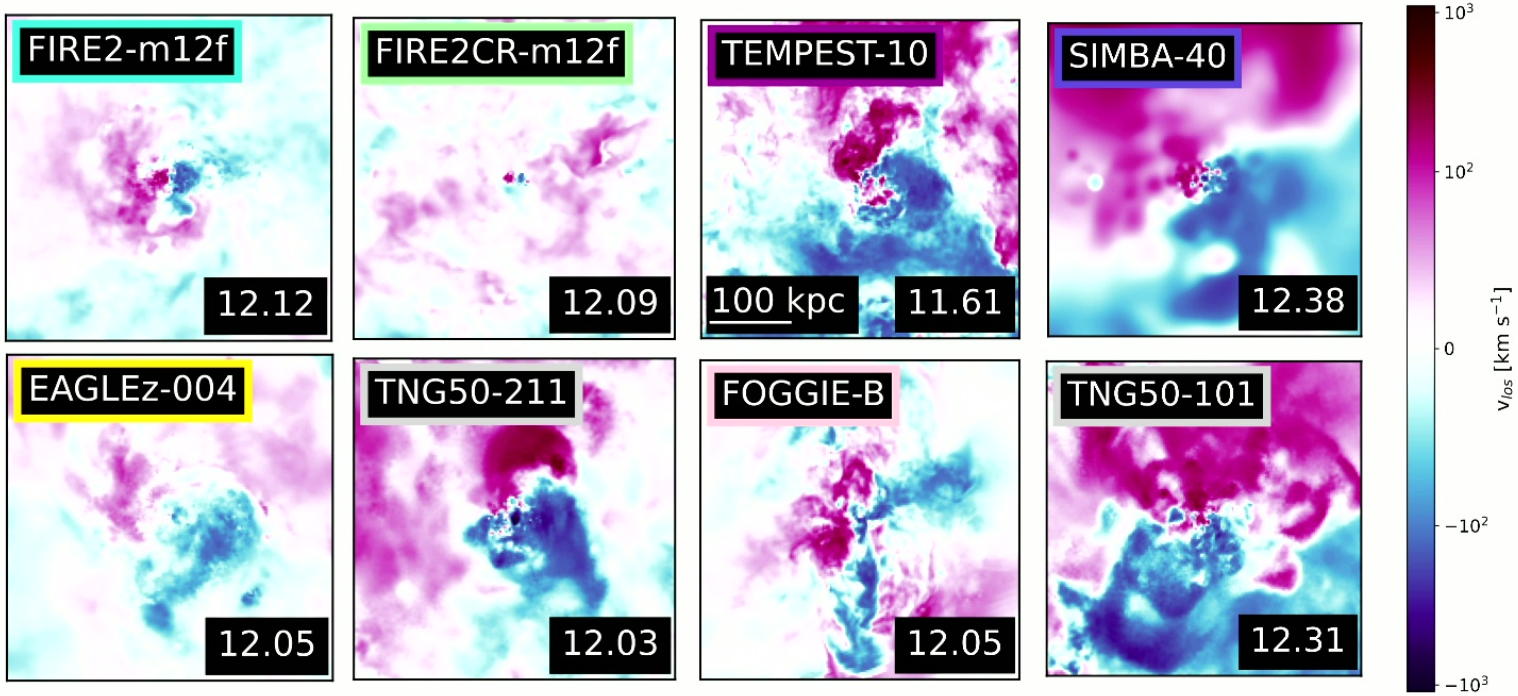


Silich et al. (2025, arXiv:2506.17440)

Bulk Velocity: Mid-On



Evidence of the bi-directional outflows on top of the rotation appears—but only if they are present!



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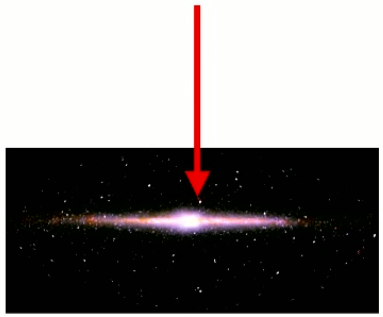
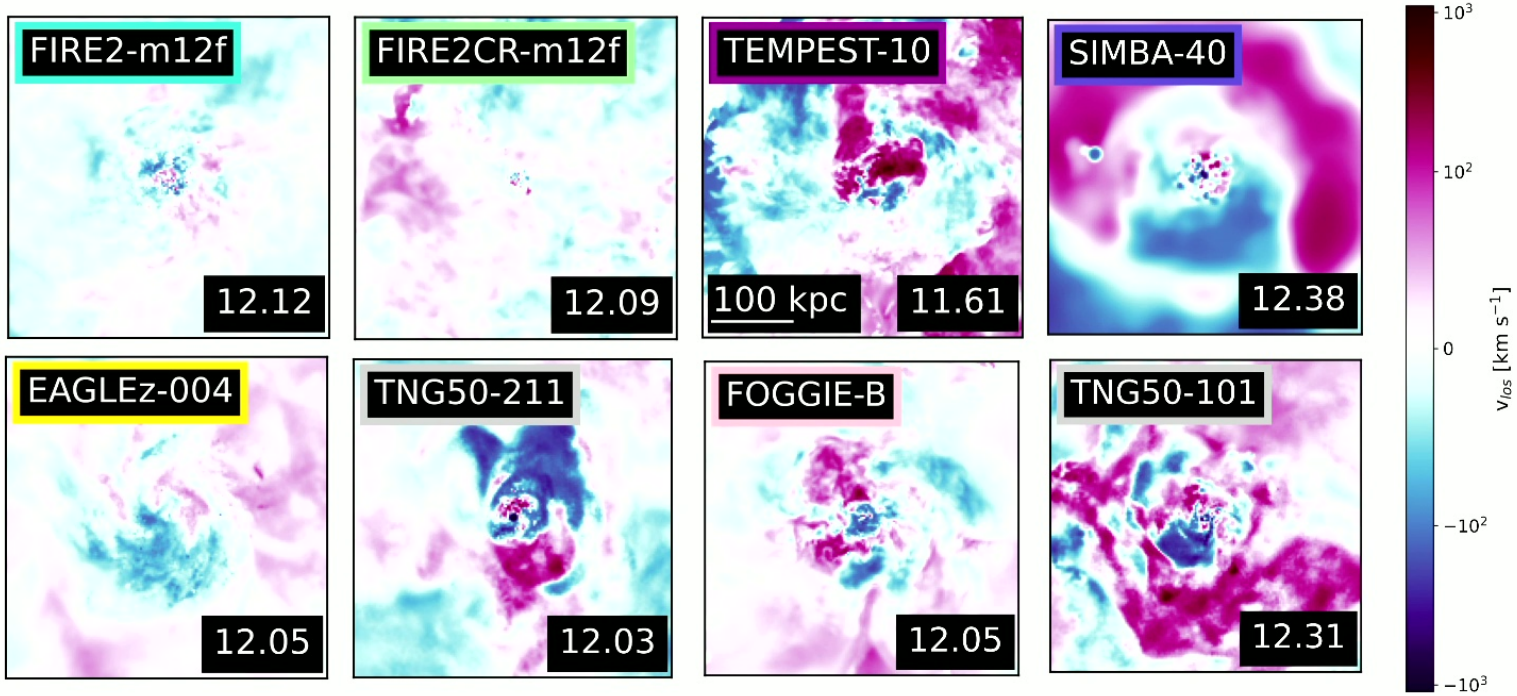
Bulk Velocity: Face-On



0th-order component of bi-directional outflows cancels out—but there's still lots of structure



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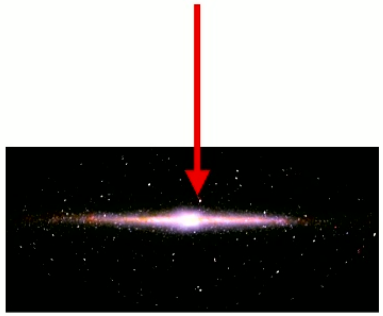
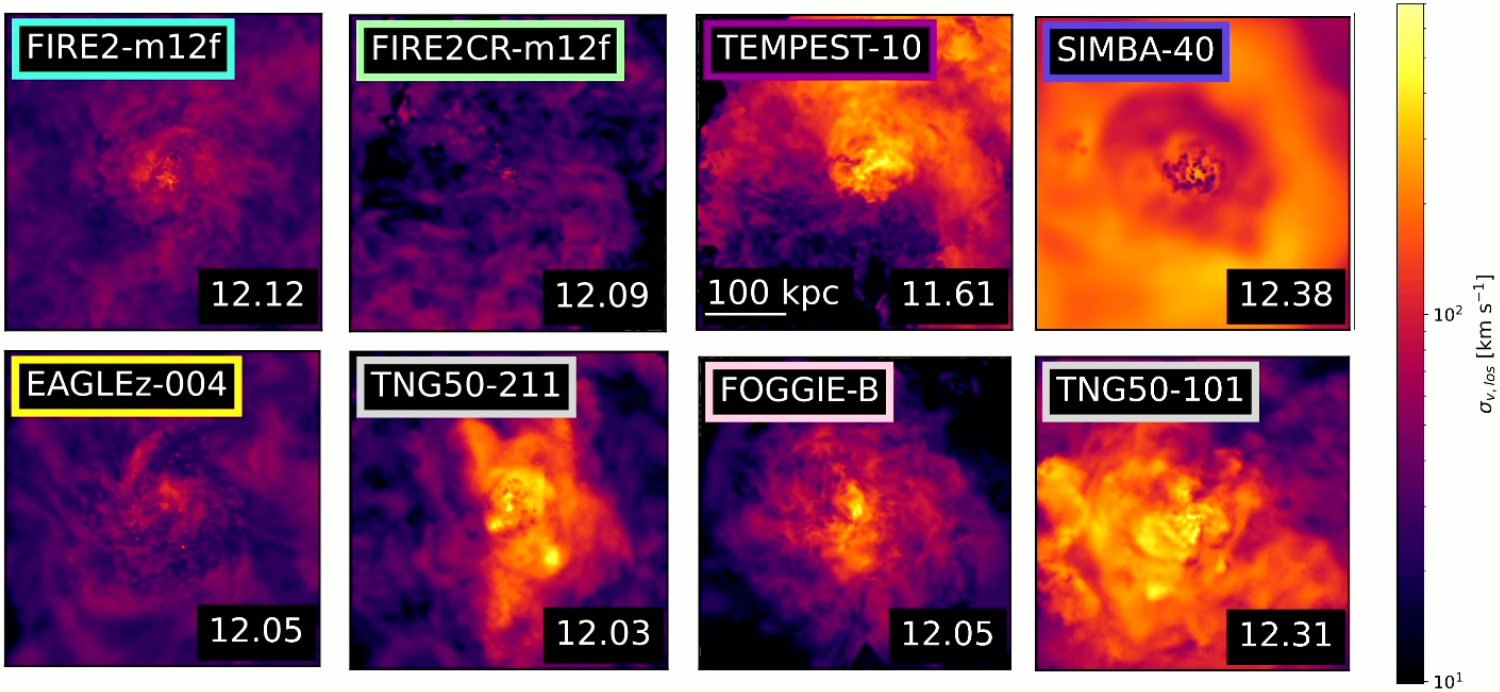
Velocity Dispersion: Face-On



Looking straight into the outflows—very large velocity dispersions, almost 1000 km/s



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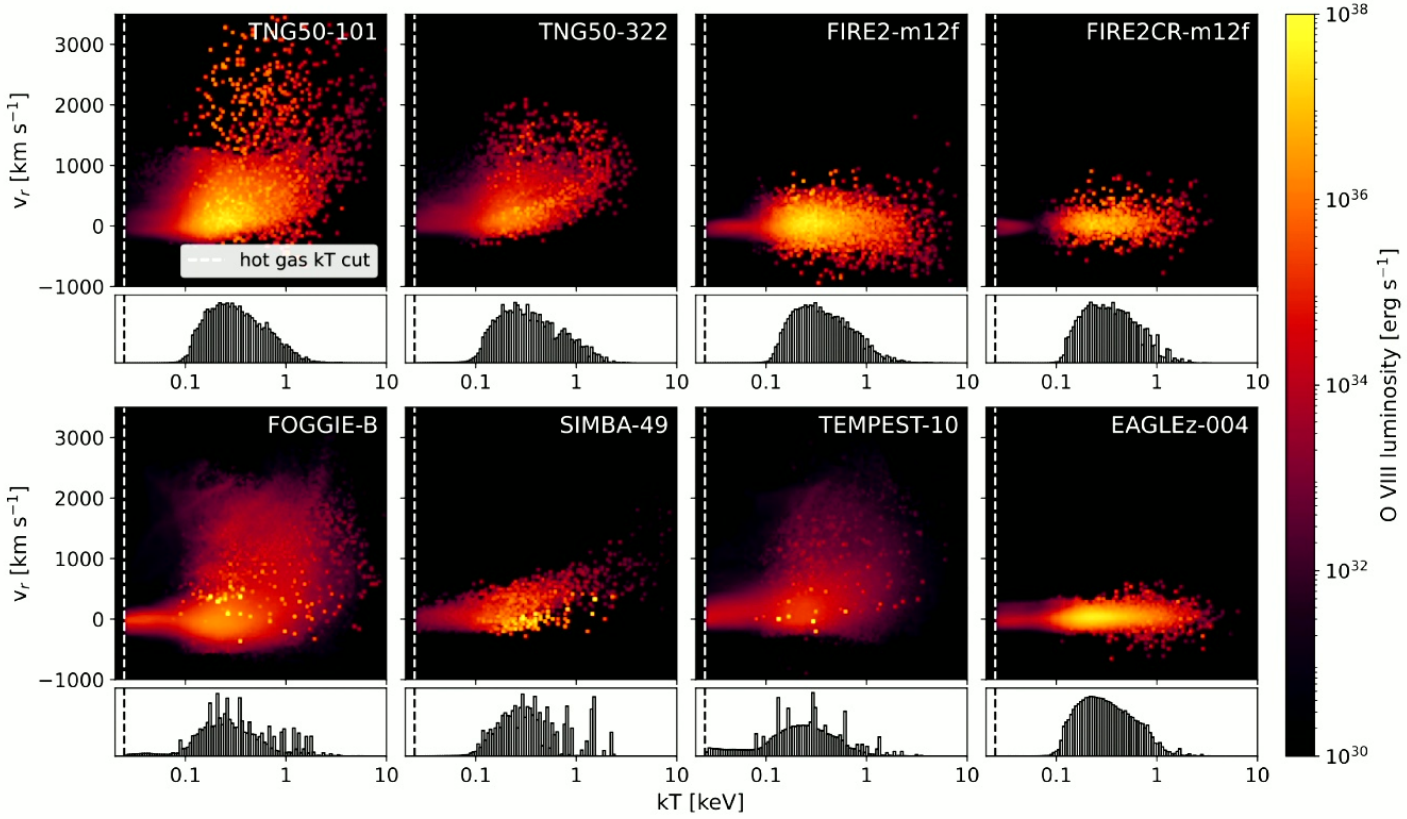
Phase Plots of Hot Gas v_r and T



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Summary

- The hot CGM, volume-filling in large galaxies, is an important part of the story of how galaxy growth and evolution is driven
- We can observe the hot CGM in X-rays—future microcalorimeter missions with higher spectral resolution will be able to use emission lines to probe its detailed properties
- From simulations, we observe that the predicted surface brightness morphology, and the kinematics are significantly affected by feedback from SMBH and stars
- But the observed differences resulting from the different feedback models are significant—thus future X-ray observations can constrain these theories
- Next step for our group is to apply similar methods to UV emission lines—stay tuned