The Co-Evolution of Supermassive Black Holes and Their Host Galaxies

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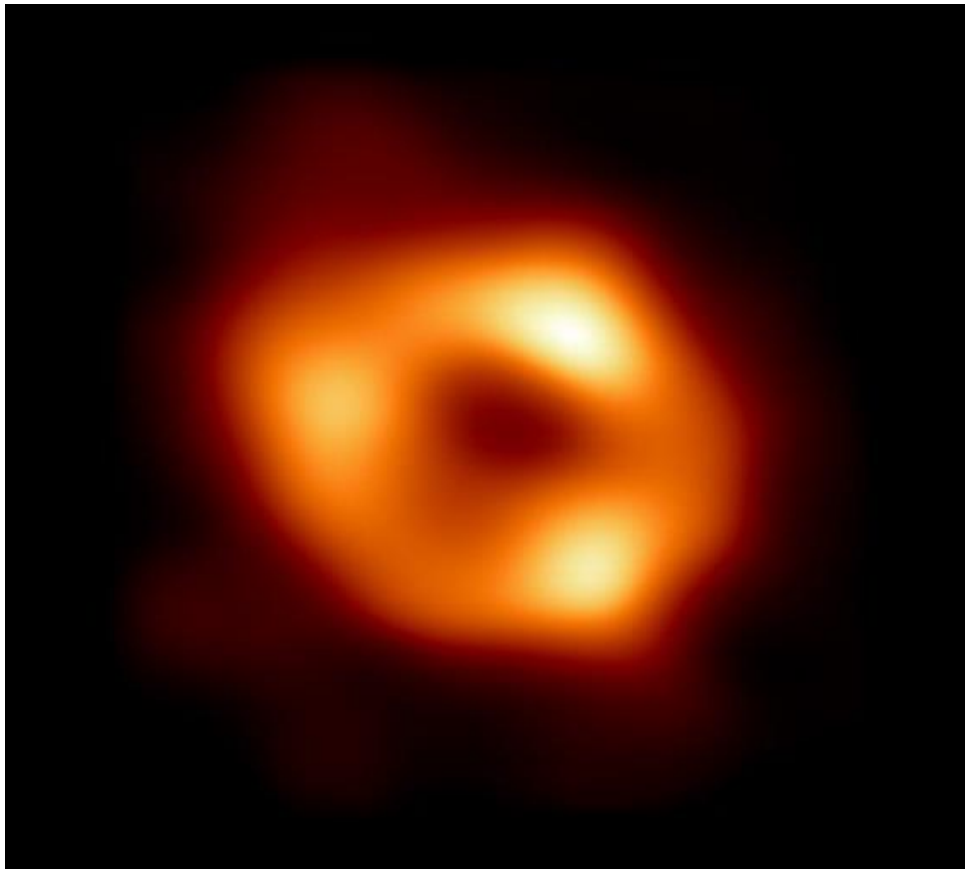
Supermassive Black Holes

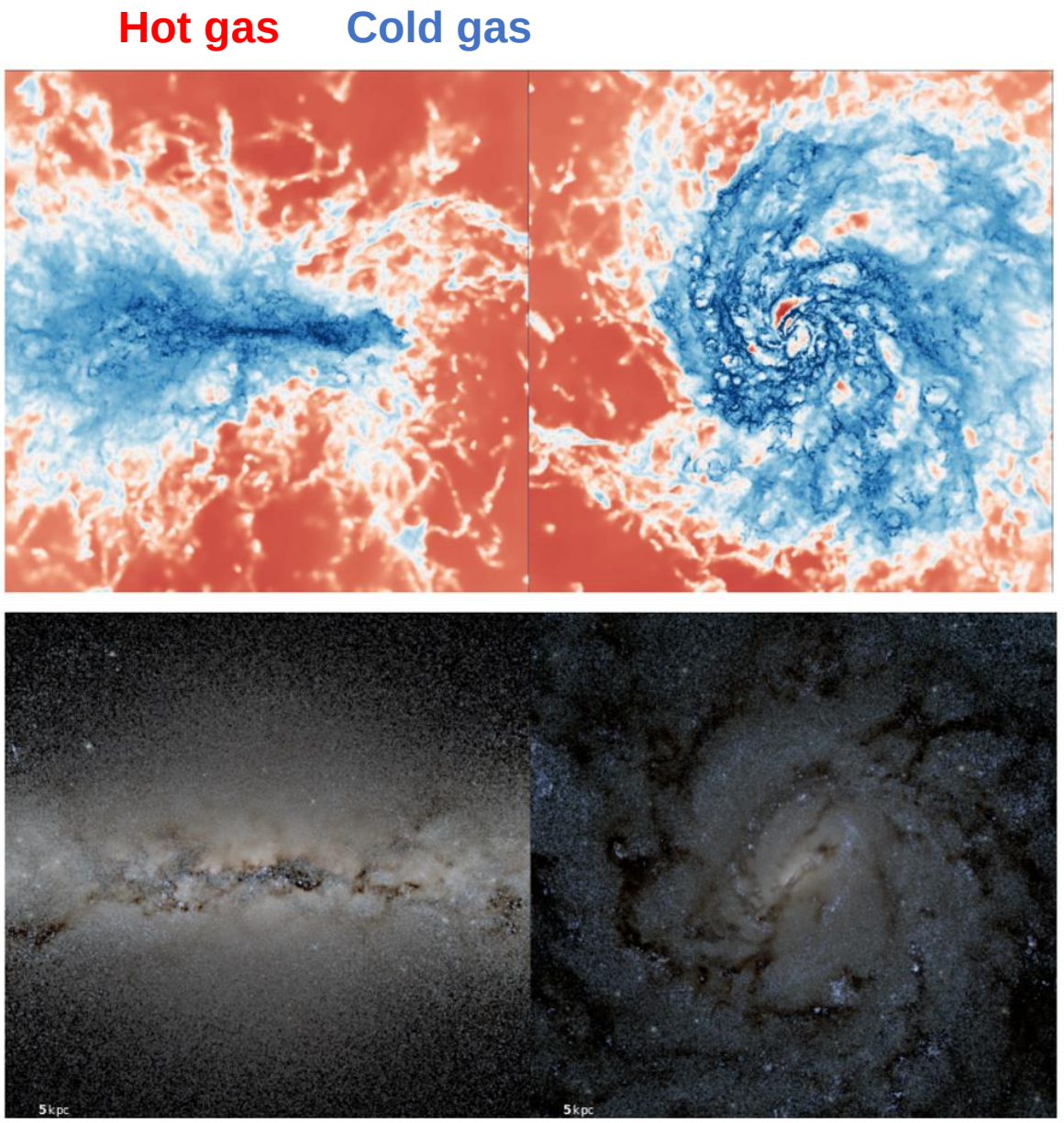
- SMBHs at the centers of galaxies, esp. massive galaxies.
- Accretion powers AGN/quasars
- Many things not well understood:
  - Formation
  - **Growth**
  - **Accretion**
  - **Feedback**

SMBH in Milky Way (Event Horizon Telescope Collaboration, 2022)



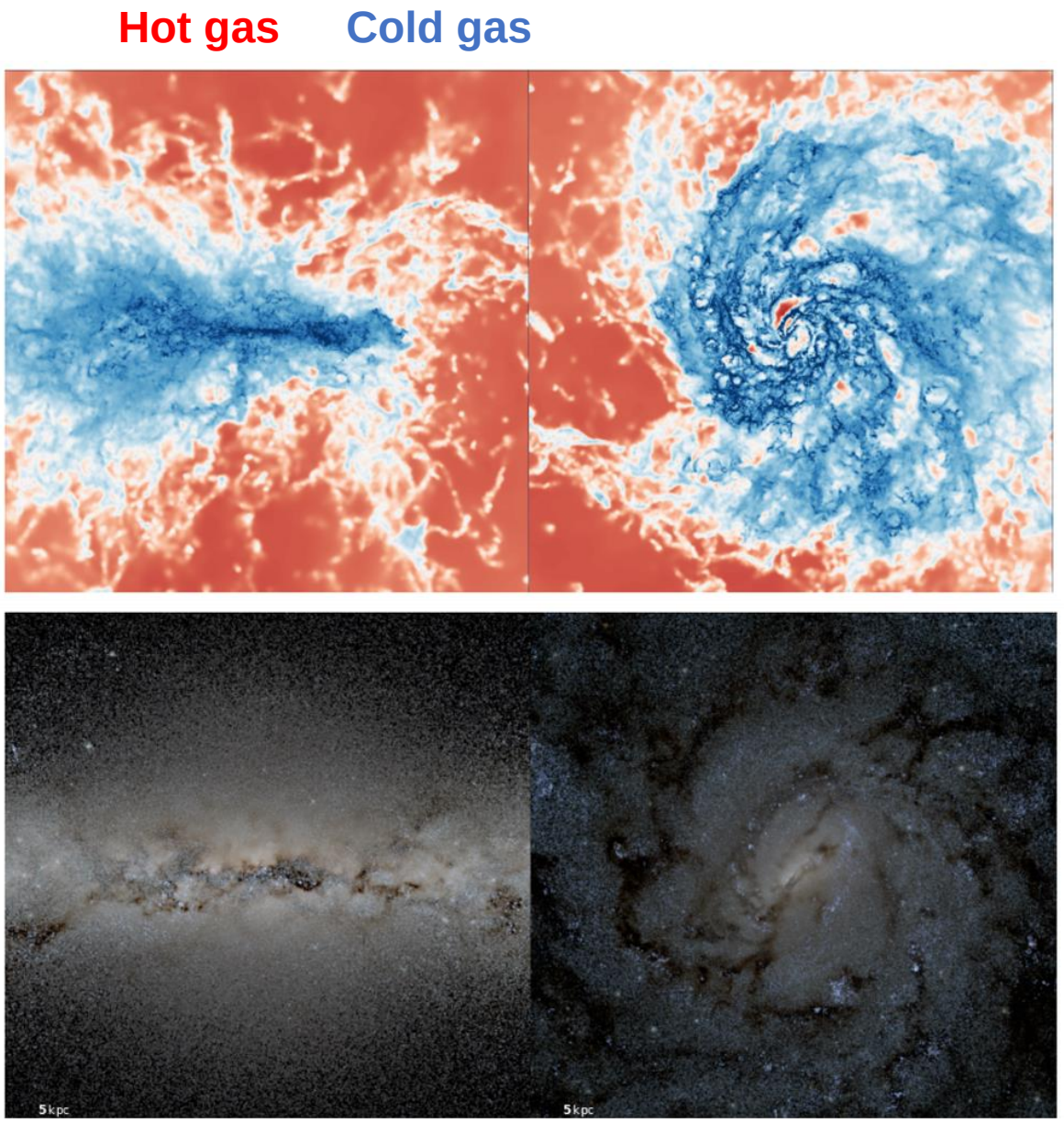
FIRE Simulations

- FIRE: Feedback In Realistic Environments
- Cosmological zoom-in simulations
- Require modeling processes over a wide range of physical and temporal scales
- Meshless finite-mass magneto-hydrodynamics solver in GIZMO (Hopkins+ 2015)
- Simulations require ~10^6 CPU-hrs, using hybrid OpenMP-MPI parallelization



FIRE Simulations

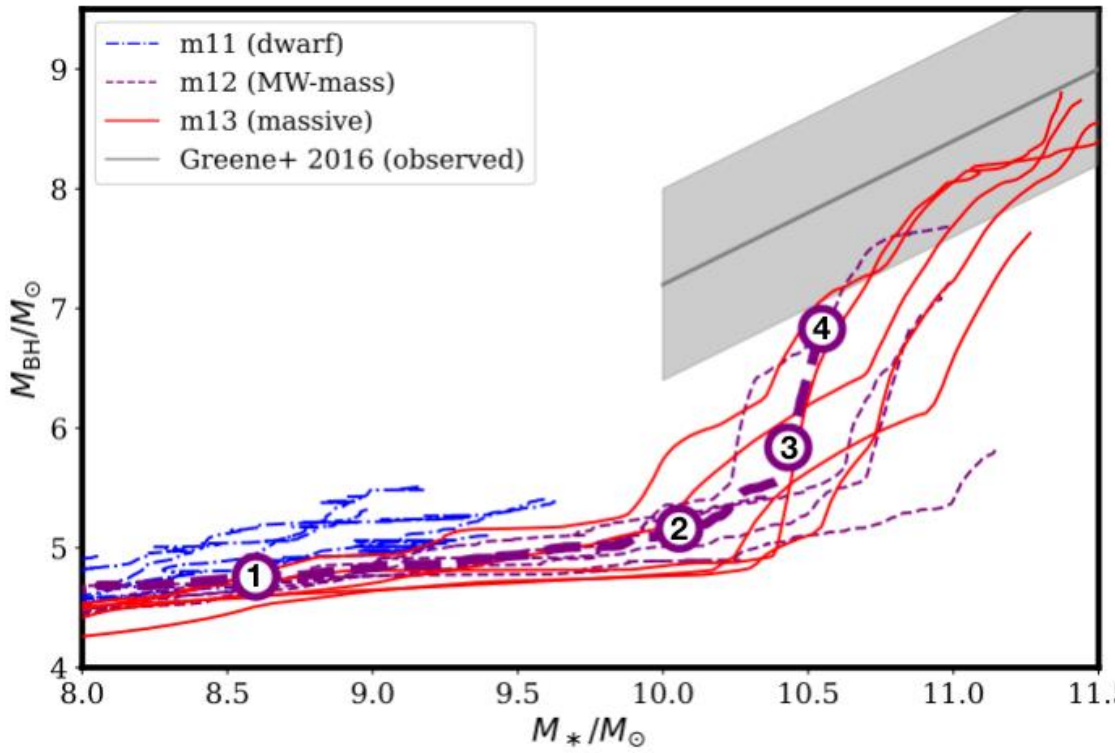
- Resolve star-forming molecular clouds and the multiphase ISM
- Star formation: out of gas that is dense, molecular, and self-gravitating
- Stellar feedback: Type Ia and II SN, stellar winds, photoionization and photoheating, radiation pressure

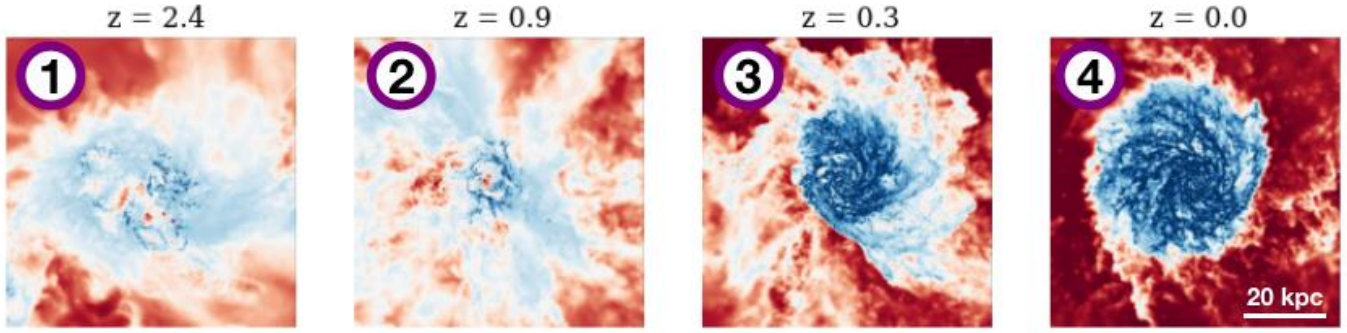


Stellar feedback regulates black hole growth

What drives BH growth?

Byrne+ 2023

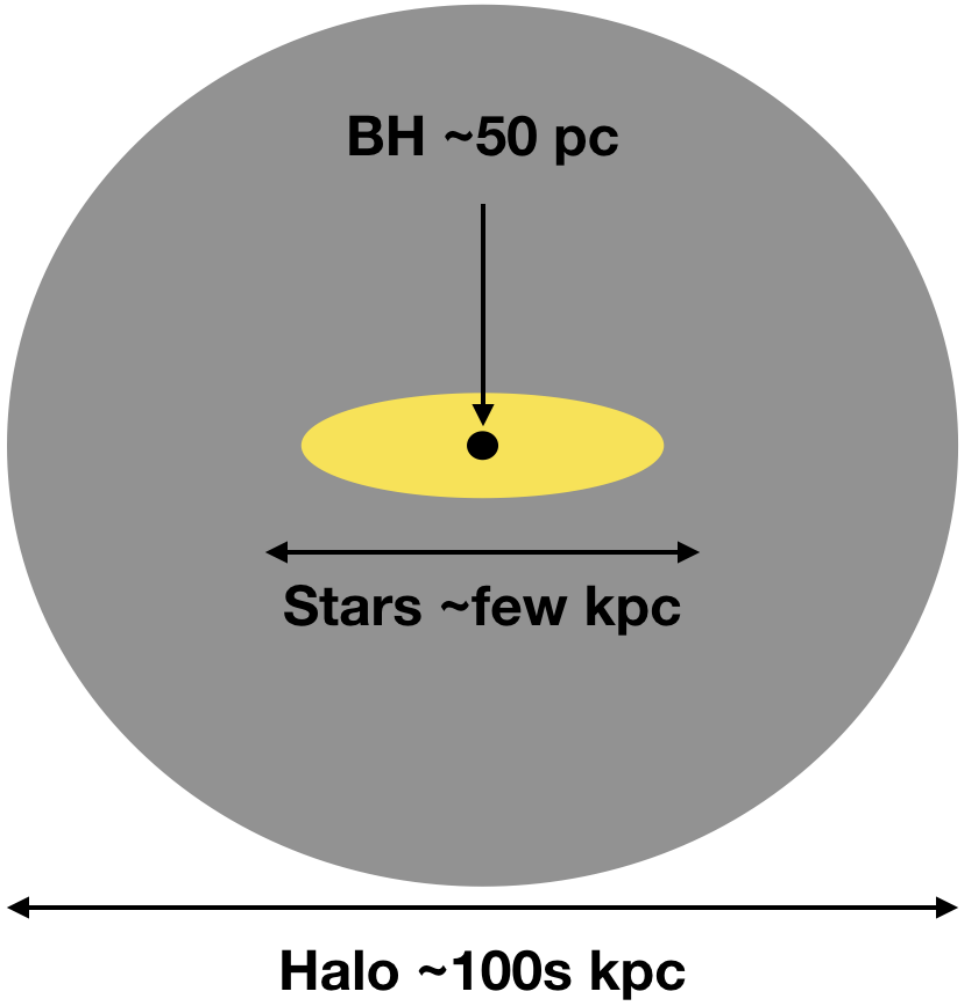




- FIRE simulations of dwarfs, MW-mass, and massive galaxies
- Undermassive at early times, then converge to observed scaling relations
- Transition to accelerated BH growth at ~$10^{10.5}$ M_{sol}

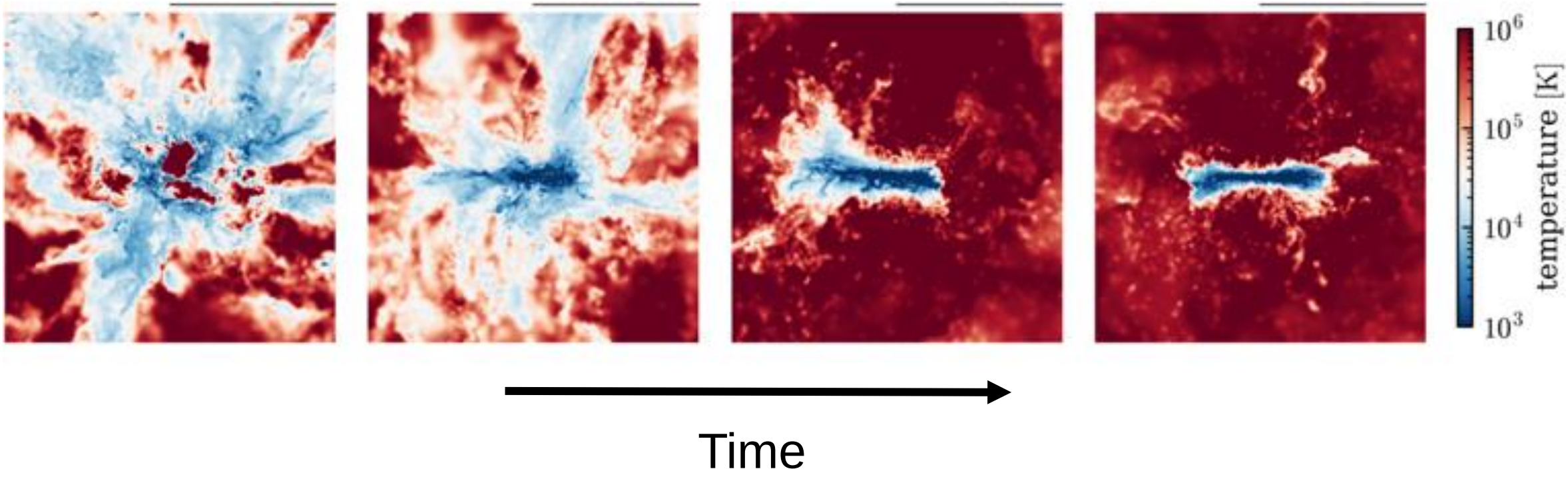
BH transition correlates to properties at a wide range of scales

- Central kpc:
  - Stellar surface density
  - Escape velocity
- Galaxy scale:
  - Stellar mass
  - Star formation bursts
- Halo scale:
  - Halo mass
  - Thermal properties of gas around the galaxy



Stellar Feedback Regulates BH growth

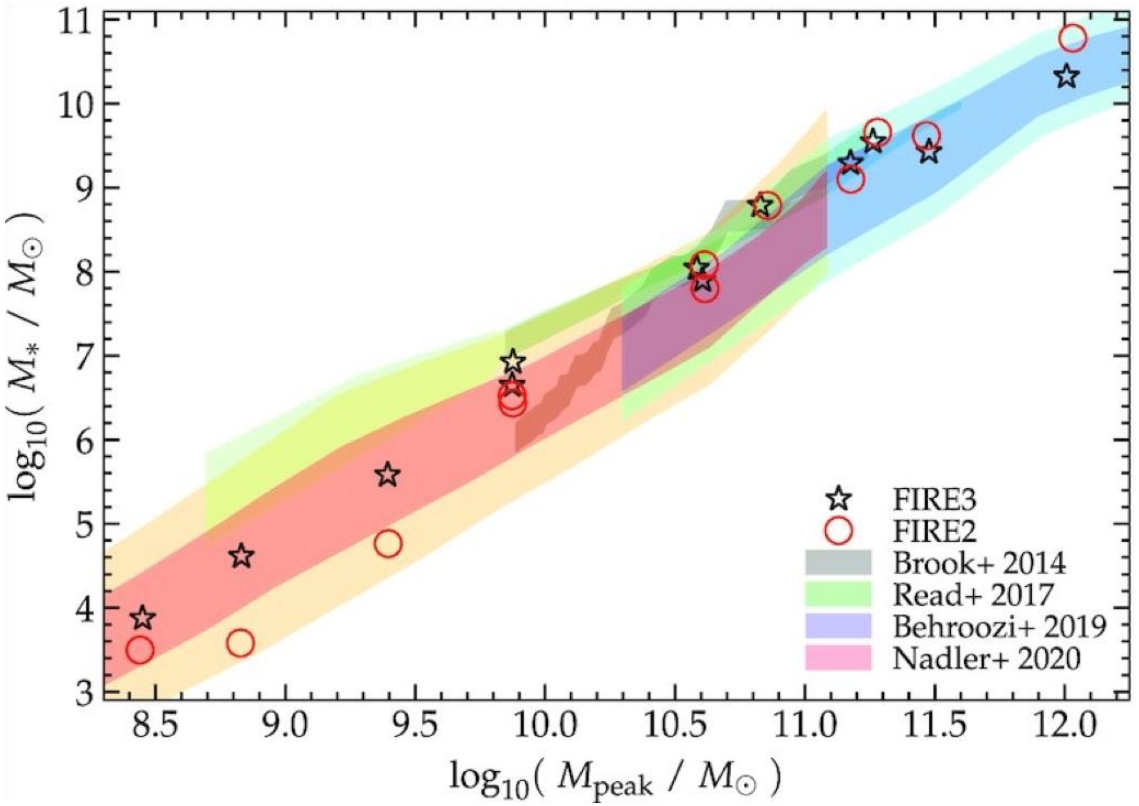
BH growth transition can be explained by the gravitational and/or pressure confinement of stellar feedback



Stern+ 2021

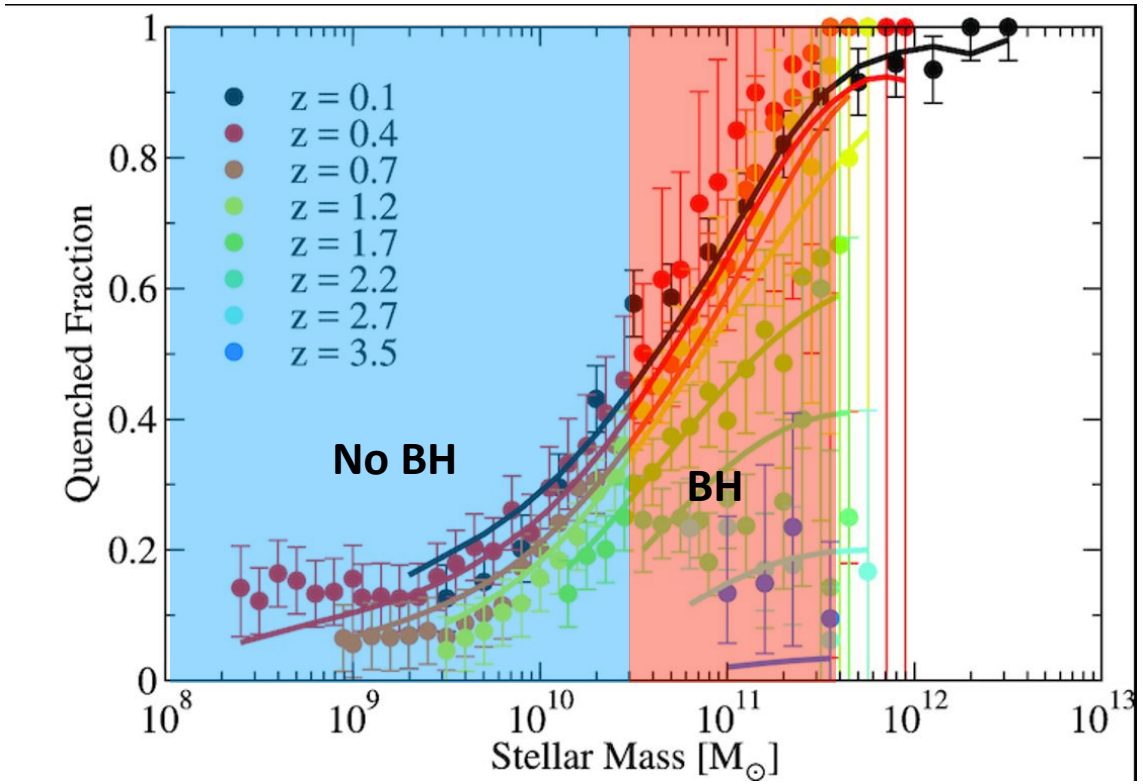
Multi-channel BH Feedback Produces Realistic Massive Galaxies in FIRE

Simulations without BH feedback can successfully produce realistic galaxies up to Milky Way mass, but fail to produce observed populations of quenched galaxies at the massive end



Hopkins+ 2023

Behroozi+ 2019

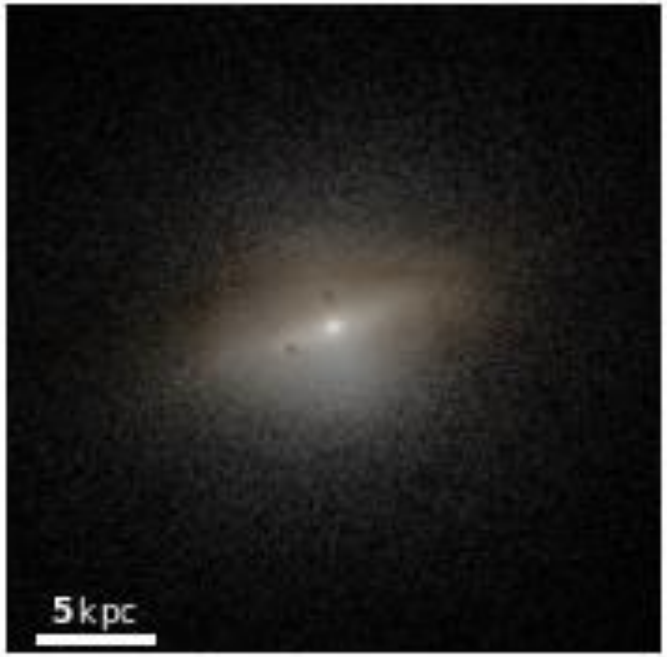


Introducing BH feedback

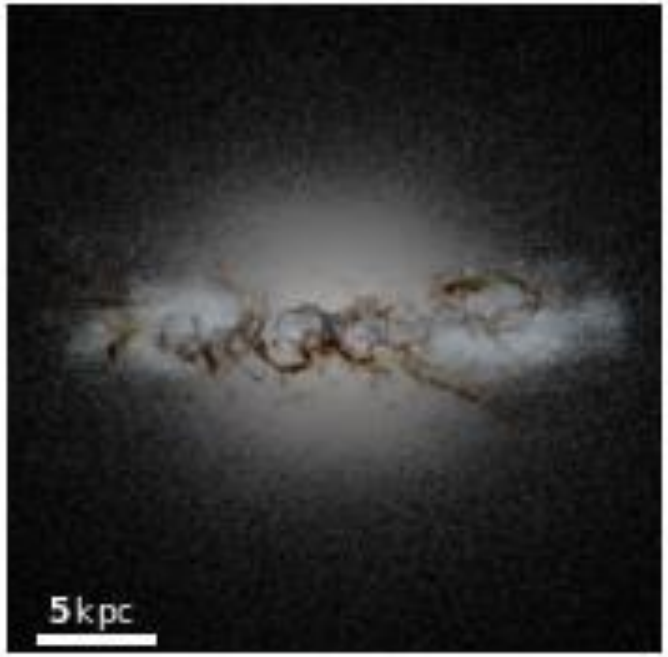
- BH prescriptions in past simulations have generally been calibrated to match observations
- FIRE: multi-channel AGN feedback with each channel tuned to known energetics from observations + first principles
  - Radiation
  - Winds
  - Cosmic rays (in some simulations)

BH feedback affects galaxy structure

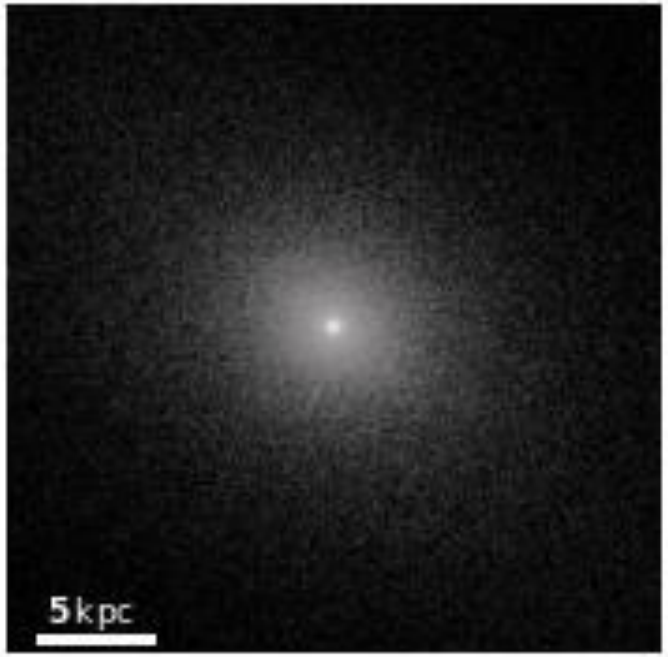
No BH



BH

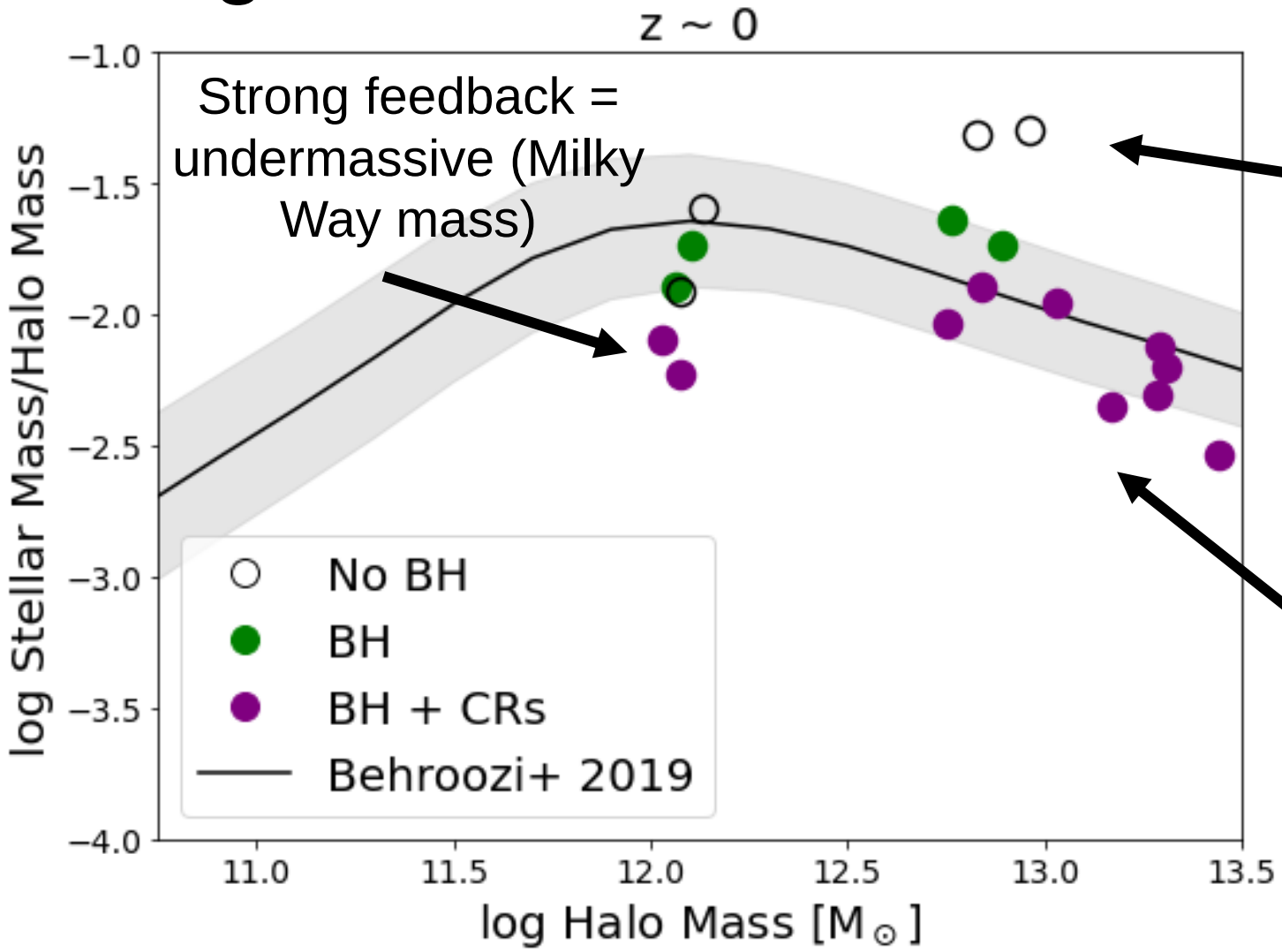


BH + CRs



Byrne+ in prep

Models with BH feedback can match local scaling relations: Stellar Mass – Halo Mass



No feedback = overmassive (massive)

Feedback models reproduce the observed SMHM relation (massive)

Byrne+ in prep

Supermassive Black Holes Co-Evolve With Their Host Galaxies

- BH growth transition corresponds in time to an increase in stellar surface density + changes in thermal properties of the CGM, which can be explained by the gravitational and/or pressure confinement of stellar feedback
- High-resolution simulations with detailed ISM physics and thermal + kinetic (+ optionally CR) feedback match local scaling relations WITHOUT fine-tuning the model to match those relations.
- Future work: How do the different channels of feedback operate and couple to the galaxy?