Cooling Flow Solutions and the Onset of Pressure Support in Galaxy-Scale Halos

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The Volume-Filling Gas Phase in Galaxy-Scale Halos

dominated by bulk flows

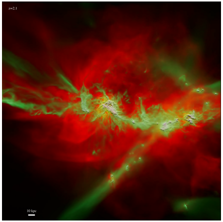
↓

at $M_{\rm h}\sim 10^{12}\,{\rm M}_\odot$ (z-independent)

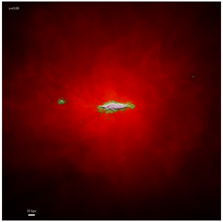
(Birnboim & Dekel '03)

↓

quasi-static, supported against gravity by thermal pressure



$M_{\rm halo} = 10^{11.5}\,{\rm M}_\odot$, $z = 2$



$M_{\rm halo} = 10^{12}\,{\rm M}_\odot$, $z \sim 0$

FIRE-2 simulations: Hopkins et al. (2018)

Outline

The *onset of pressure support* in galaxy-scale halos according to...

1. analytic cooling flow theory
2. idealized CGM simulations
3. the *FIRE* cosmological simulations
4. observations

complexity

Outline

The *onset of pressure support* in galaxy-scale halos according to...

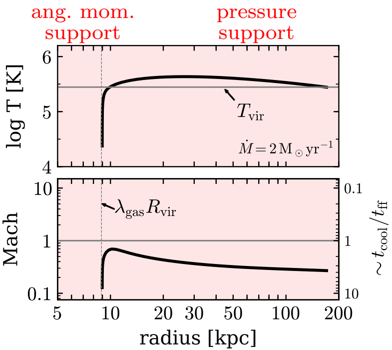
1. analytic cooling flow theory
2. idealized CGM simulations
3. the *FIRE* cosmological simulations
   result: coincides with bursty SF → steady SF transition
4. observations

complexity ↓

Cooling Flow Solutions for the Hot CGM

- Steady-state solutions for radiating gas in const. potential (Mathews & Bregman '78)
- *Two classes* of solutions separated by a *critical inflow rate* $\dot{M}_{\rm crit}$:

$\dot{M} < \dot{M}_{\rm crit}$



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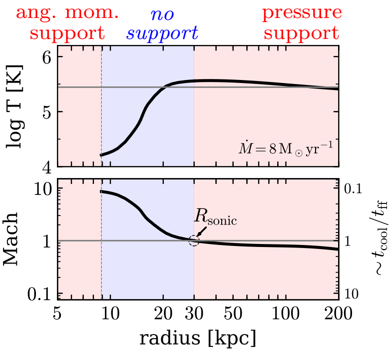

Parameters: $M_{\rm h} = 10^{11.5}{\rm M}_\odot$, $z = 0$, ${\rm Z}_\odot/3$, gas spin $\lambda_{\rm gas} = 0.035$

Stern et al. (in prep.)

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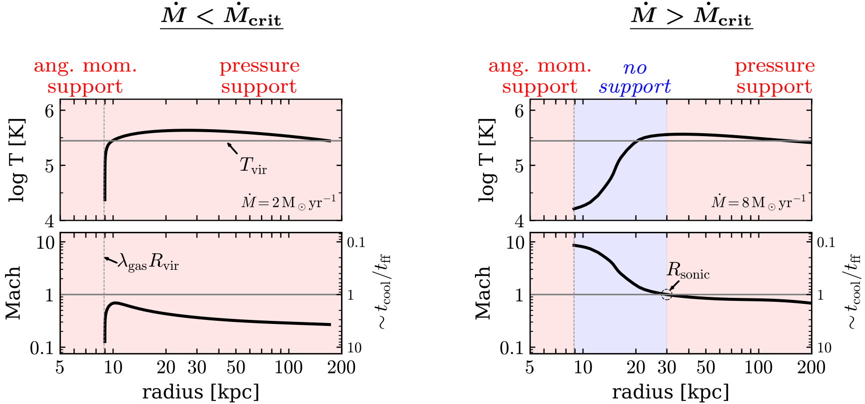

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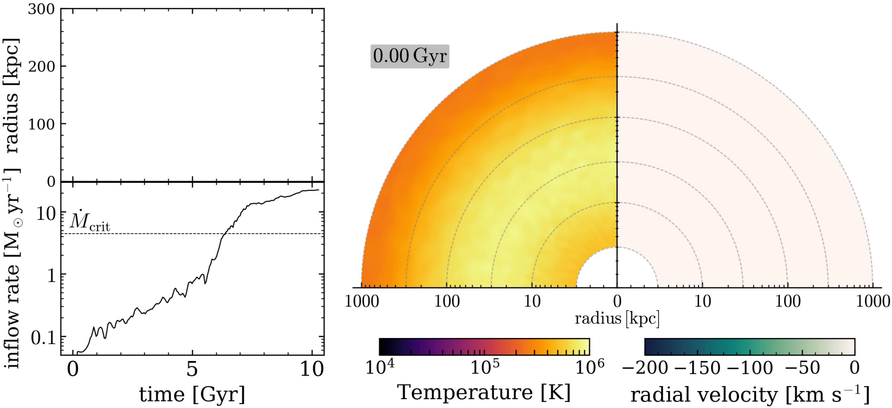
Stern et al. (in prep.)

$\dot{M}_{\rm crit}$ derived from $R_{\rm sonic} = \lambda_{\rm gas} R_{\rm vir}$

A Critical Inflow Rate in Idealized 3D Simulations



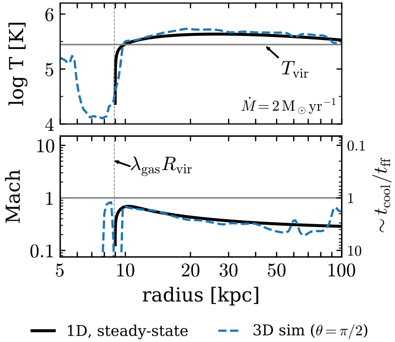
$M_h = 10^{11.5}\,M_\odot,\ z = 0,\ Z_\odot/3$

Stern et al. (in prep.); sims based on Fielding et al. (2017)

*when inflow rate exceeds $\dot{M}_{crit}$ hot CGM collapses to a cool **supersonic** flow*

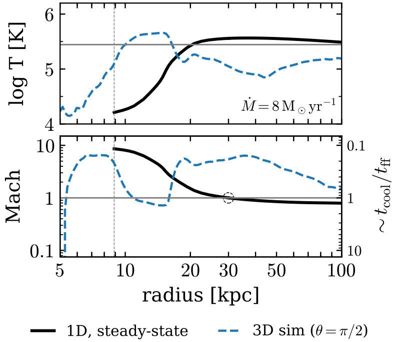
Cooling Flow Solutions vs. Idealized CGM Simulations

$\dot{M} < \dot{M}_{\mathbf{crit}}$



realized in 3D sims

$\dot{M} > \dot{M}_{\mathbf{crit}}$



not realized in 3D sims

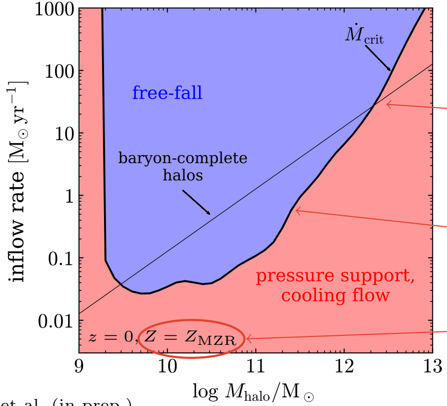
Stern et al. (in prep.)

Reformulation of Condition for CGM Pressure Support

- $\dot{M} < \dot{M}_{\rm crit}$: pressure support
- $\dot{M} > \dot{M}_{\rm crit}$: free-fall

$\dot{M}_{\rm crit}$ is the maximum accretion rate of the 'hot' mode

larger halo gas mass ⟶



Stern et al. (in prep.)

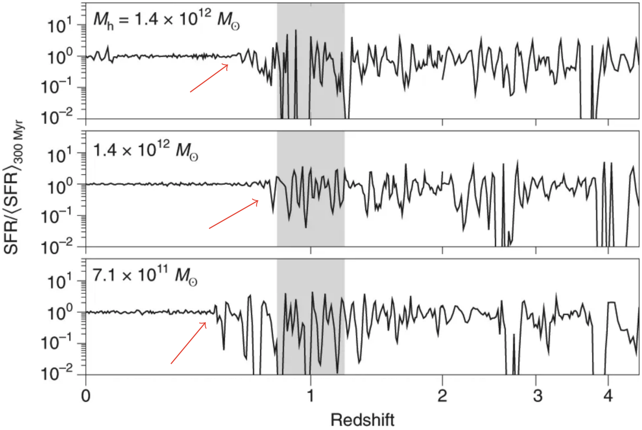
intersection at $\sim\ 10^{12}\,\mathrm{M}_\odot$ as threshold in Birnboim & Dekel

in *low-mass halos* pressure support possible if CGM is *baryon-depleted*

$\dot{M}_{\rm crit}$ set by conditions at *galaxy scale*

Onset of pressure support in the *FIRE* cosmological simulations

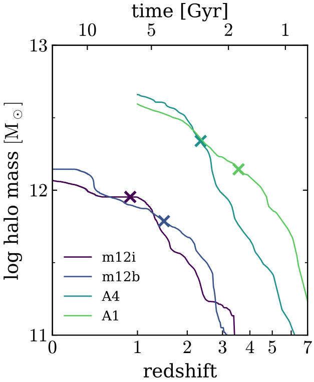
A Puzzle in the FIRE 'Zoom-in' Simulations

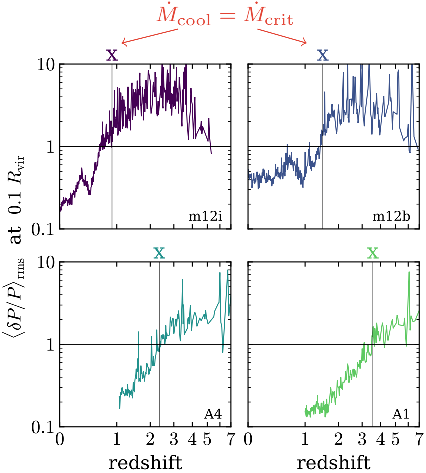


Faucher-Giguère (2018); see also Muratov et al. (2015)

Sharp *transition between bursty and steady star formation*

Onset of Pressure Support in FIRE using $\dot{M}_{\rm crit}$

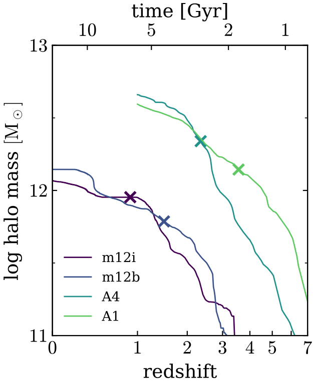




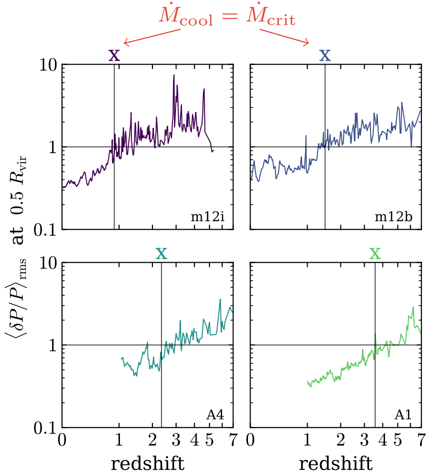
Stern et al. (in prep.)

when $\dot{M}_{\rm cool} = \dot{M}_{\rm crit}$ halo pressure becomes ***uniform***

Onset of Pressure Support in FIRE using $\dot{M}_{\rm crit}$

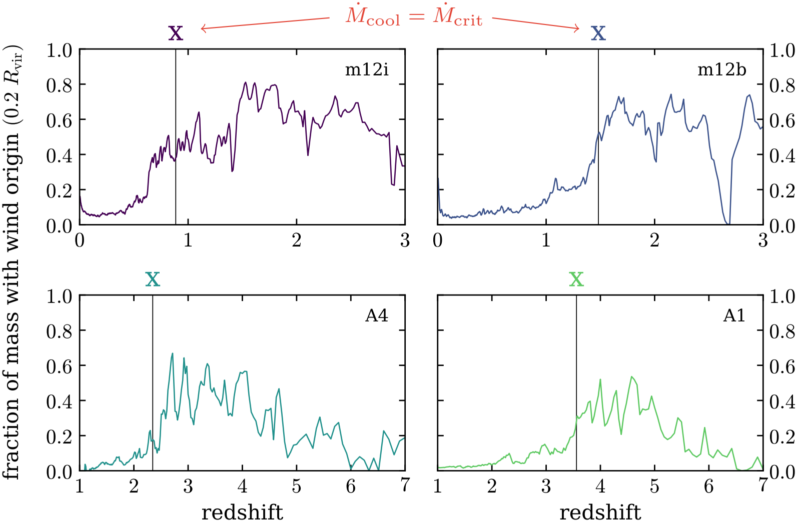


Stern et al. (in prep.)



when $\dot{M}_{\rm cool} = \dot{M}_{\rm crit}$ halo pressure becomes ***uniform***

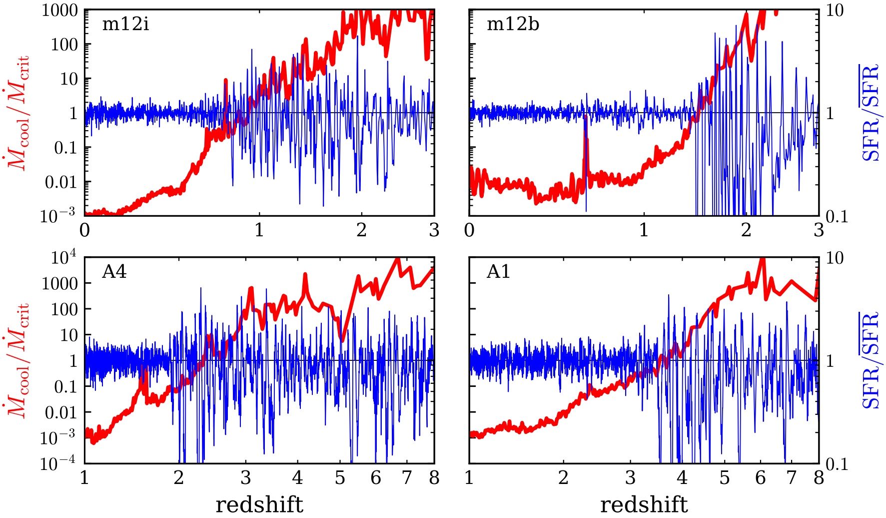
Pressure Support versus CGM composition



Stern et al. (in prep.); wind fraction from Hafen+18

CGM wind content drops after onset of pressure support

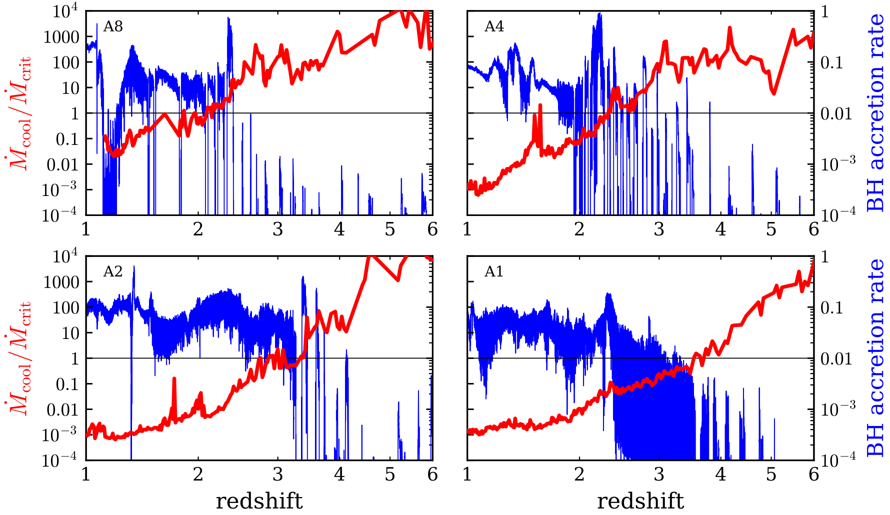
Pressure Support versus the Star Formation Rate



Stern et al. (in prep.)

$\dot{M}_{\rm cool} = \dot{M}_{\rm crit}$ coincides with transition to steady SFR

Pressure Support versus Black Hole Growth

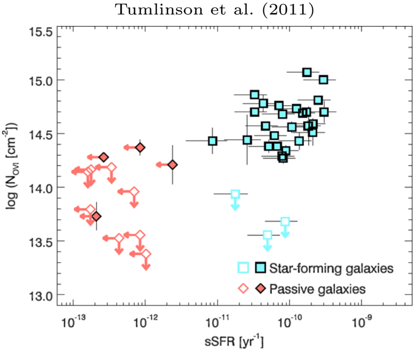


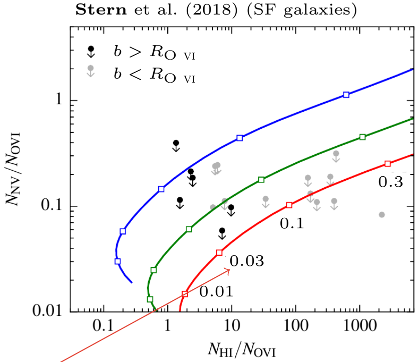
Byrne et al. (in prep.); $\dot{M}_{\rm BH}$ from Angles-Alcazar+17

$\dot{M}_{\rm cool} = \dot{M}_{\rm crit}$ coincides with onset of significant BH growth

Onset of pressure support in observations

Pressure Support in the Halos of Blue and Red Galaxies





line ratios consistent with **low gas pressure** compared to virialized halo

⇒ O VI *dichotomy can be explained with free-falling CGM around blue galaxies, pressure-supported CGM around red galaxies*

Summary

1. New derivation of condition for pressure support using cooling flows

2. Identified onset of pressure support in *FIRE*. Coincides with
   - transition from *bursty* to *steady* star formation
   - drop in CGM wind content
   - onset of BH growth

3. Observed circumgalactic O VI dichotomy consistent with:
   blue galaxies → before onset of pressure support
   red galaxies → after onset of pressure support