Two Modes of Accretion onto $\sim L^*$ Galaxies

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Collaborators:
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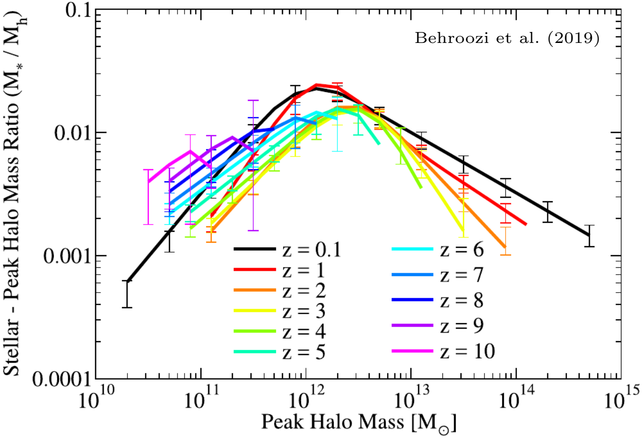
Papers:
Stern et al. 2018, 2019a,b: arXiv:1909.07402; MNRAS 488 2549; ApJ 865 91

How the Global CGM Structure affects Star Formation

$t_{\rm cool} \ll t_{\rm ff}$	$t_{\rm cool} \sim t_{\rm ff}$	$t_{\rm cool} \gg t_{\rm ff}$
free-fall, cold flows	?	∼HSE, cooling flows



refs:
Rees&Ostriker '77; White&Rees '78; Birnboim&Dekel '03; Dusan+2005, 2009; Nelson+2013; Fielding+2017

Outline

The transition between *free-fall* and *cooling flows* in:

1. Steady-state solutions for halo gas
2. Idealized hydro simulations
3. The *FIRE* cosmological simulations
4. Observations

complexity

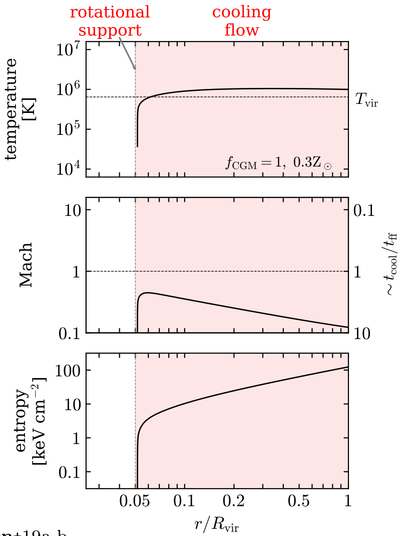
Equations

$$\dot{M} = -4\pi r^2 \rho v$$

$$\frac{1}{2}\frac{dv^2}{dr} = -\frac{1}{\rho}\frac{dP}{dr} - g + \frac{j^2}{r^3}$$

$$\frac{d\ln(P/\rho^\gamma)}{dr} = \frac{1}{-v \cdot t_{\rm cool}}$$

Solution for $\log M_{\rm h} = 12.2, \ z = 0$



Stern+19a,b

Steady-state Solutions for the Volume-Filling Phase

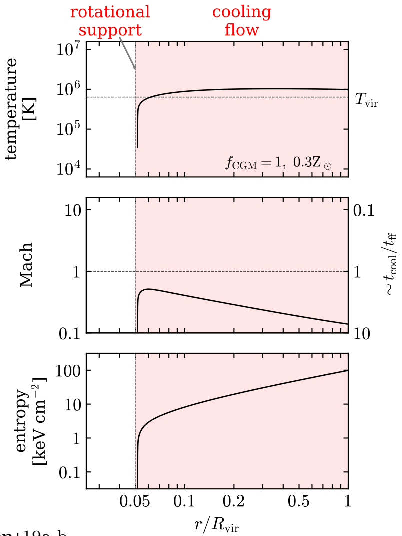
Equations

$$\dot{M} = -4\pi r^2 \rho v$$

$$\frac{1}{2}\frac{dv^2}{dr} = -\frac{1}{\rho}\frac{dP}{dr} - g + \frac{j^2}{r^3}$$

$$\frac{d\ln(P/\rho^\gamma)}{dr} = \frac{1}{-v \cdot t_{\rm cool}}$$

Solution for $\log M_{\rm h} = 12.1,\ z = 0.3$



Stern+19a,b

Equations

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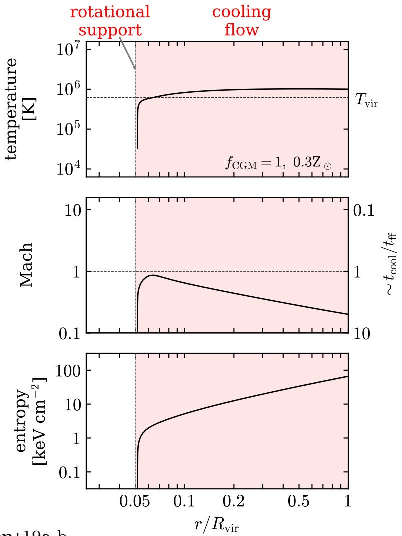
$$\frac{d\ln(P/\rho^\gamma)}{dr} = \frac{1}{-v \cdot t_{\rm cool}}$$

Solution for $\log M_{\rm h} = 12.0,\ \ z = 0.6$



Stern+19a,b

Steady-state Solutions for the Volume-Filling Phase

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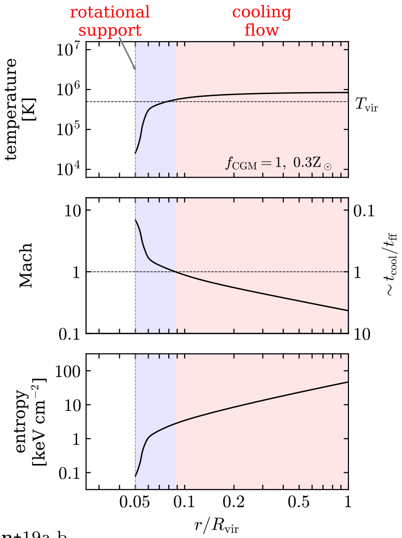
Solution for $\log M_{\rm h} = 11.9,\ \ z = 1$



Stern+19a,b

Steady-state Solutions for the Volume-Filling Phase

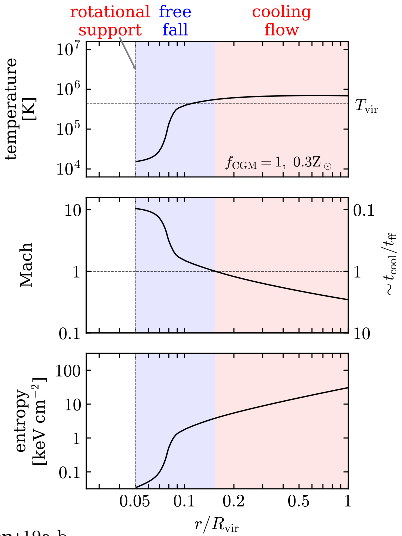
Equations

$$\dot{M} = -4\pi r^2 \rho v$$

$$\frac{1}{2}\frac{dv^2}{dr} = -\frac{1}{\rho}\frac{dP}{dr} - g + \frac{j^2}{r^3}$$

$$\frac{d\ln(P/\rho^\gamma)}{dr} = \frac{1}{-v \cdot t_{\rm cool}}$$

Solution for $\log M_{\rm h} = 11.6,\ z = 1.5$



Stern+19a,b

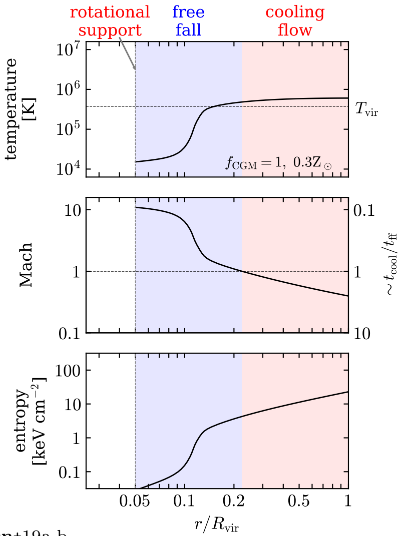
Equations

$$\dot{M} = -4\pi r^2 \rho v$$

$$\frac{1}{2}\frac{dv^2}{dr} = -\frac{1}{\rho}\frac{dP}{dr} - g + \frac{j^2}{r^3}$$

$$\frac{d\ln(P/\rho^\gamma)}{dr} = \frac{1}{-v \cdot t_{\rm cool}}$$

Solution for $\log M_{\rm h} = 11.4, \ z = 2.2$



Stern+19a,b

Steady-state Solutions for the Volume-Filling Phase

Equations

$$\dot{M} = -4\pi r^2 \rho v$$

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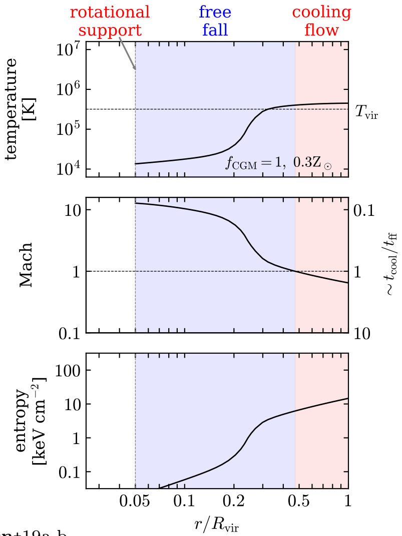
$$\frac{d\ln(P/\rho^\gamma)}{dr} = \frac{1}{-v \cdot t_{\rm cool}}$$

Solution for $\log M_{\rm h} = 11.2, \;\; z = 3$



Stern+19a,b

Steady-state Solutions for the Volume-Filling Phase

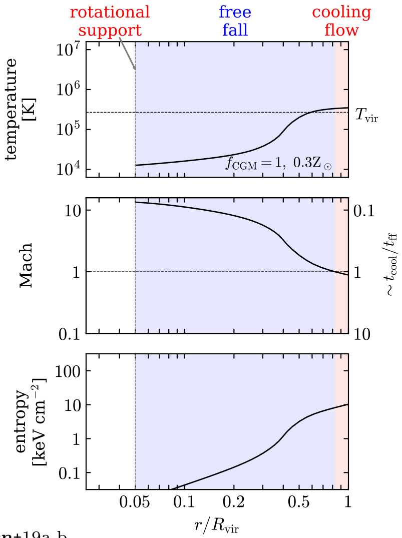
Equations

$$\dot{M} = -4\pi r^2 \rho v$$

$$\frac{1}{2}\frac{dv^2}{dr} = -\frac{1}{\rho}\frac{dP}{dr} - g + \frac{j^2}{r^3}$$

$$\frac{d\ln(P/\rho^\gamma)}{dr} = \frac{1}{-v \cdot t_{\rm cool}}$$

Solution for $\log M_{\rm h} = 11.0, \ \ z = 4$



Stern+19a,b

Steady-state Solutions for the Volume-Filling Phase

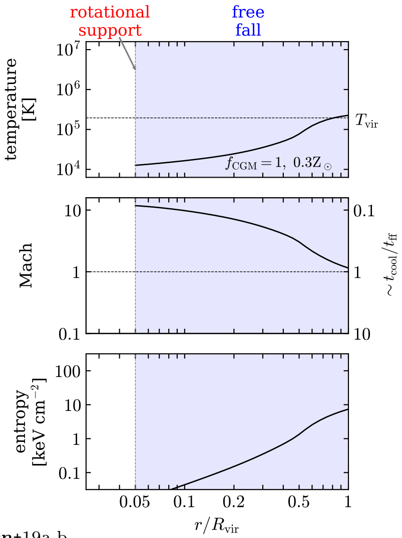
Equations

$$\dot{M} = -4\pi r^2 \rho v$$

$$\frac{1}{2}\frac{dv^2}{dr} = -\frac{1}{\rho}\frac{dP}{dr} - g + \frac{j^2}{r^3}$$

$$\frac{d\ln(P/\rho^\gamma)}{dr} = \frac{1}{-v \cdot t_{\rm cool}}$$

Solution for $\log M_{\rm h} = 10.7,\ \ z = 5$



Stern+19a,b

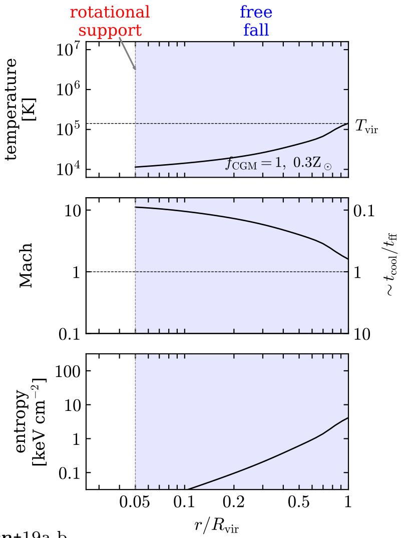
Equations

$$\dot{M} = -4\pi r^2 \rho v$$

$$\frac{1}{2}\frac{dv^2}{dr} = -\frac{1}{\rho}\frac{dP}{dr} - g + \frac{j^2}{r^3}$$

$$\frac{d\ln(P/\rho^\gamma)}{dr} = \frac{1}{-v \cdot t_{\rm cool}}$$

Solution for $\log M_{\rm h} = 10.4, \;\; z = 7$



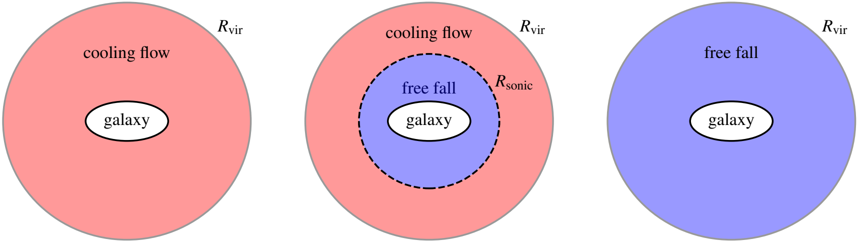
Stern+19a,b

Three Types of Solutions for the Global CGM Structure

$t_{\rm cool} > t_{\rm ff}$

$t_{\rm cool} < t_{\rm ff}$ at small r
$t_{\rm cool} > t_{\rm ff}$ at large r

$t_{\rm cool} < t_{\rm ff}$



Stern+19b

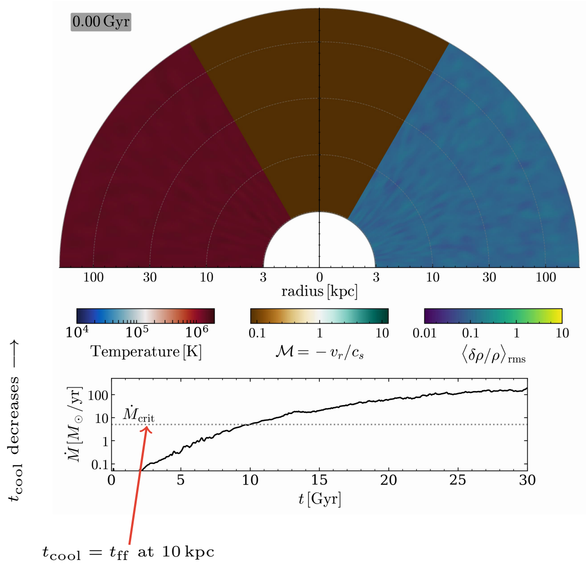
accretion mode *onto galaxy* determined by $t_{\rm cool}/t_{\rm ff}$ at *galaxy outskirts*

The Global CGM Structure in 3D Idealized Simulations

Conclusions from steady-state solutions supported by idealized simulations

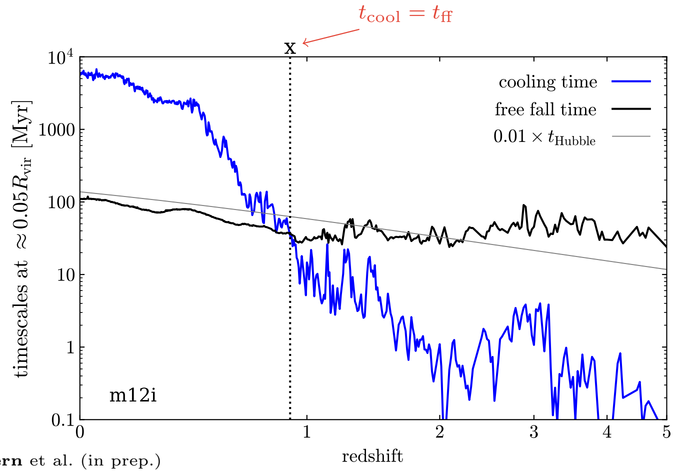
Thermal instabilities develop only in free-falling gas where $t_{\rm cool} < t_{\rm ff}$

(see Balbus & Soker '89)



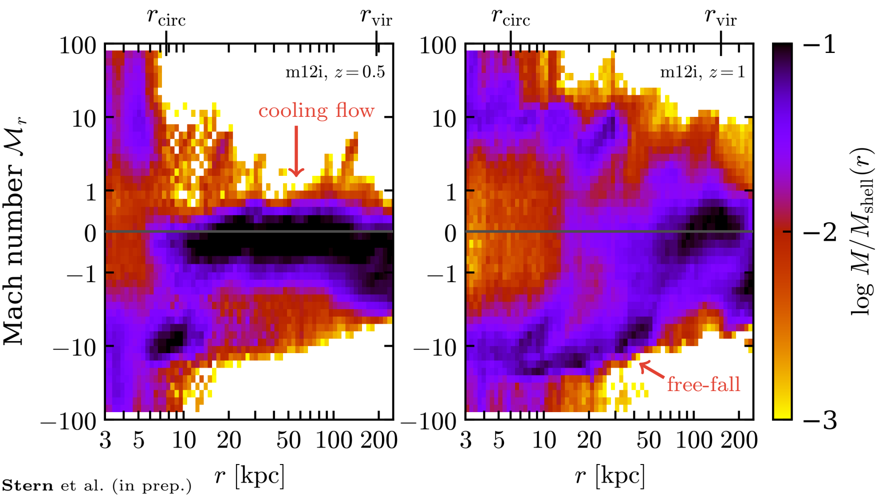
Stern+19b, sims by D. Fielding

Identification of Transition in FIRE 'Zoom' Simulations



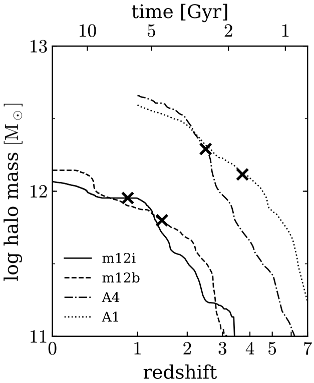
Stern et al. (in prep.)

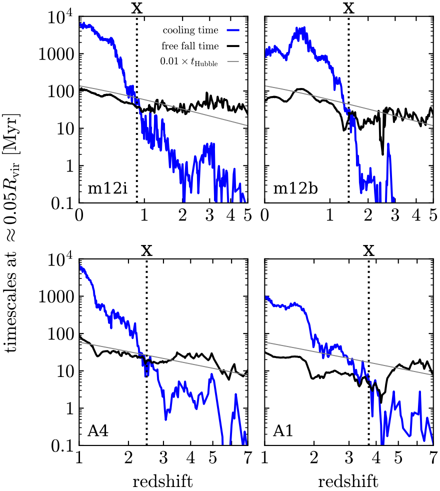
A Major Change in the Global Structure of the CGM



Stern et al. (in prep.)

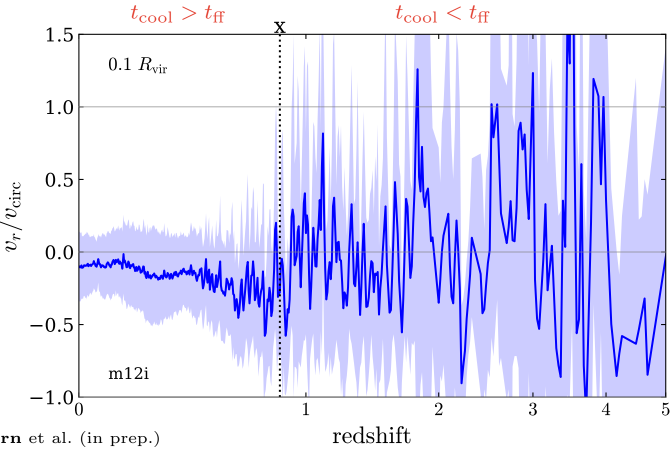
$\log M_{\rm h} = 12; z = 0.5; \frac{t_{\rm cool}}{t_{\rm ff}} \approx 3$ $\log M_{\rm h} = 11.9; z = 1; \frac{t_{\rm cool}}{t_{\rm ff}} \approx \frac{1}{3}$





Stern et al. (in prep.)

SF-driven outflows cease when $t_{\rm cool} > t_{\rm ff}$ at $\approx 0.05 R_{\rm vir}$



Stern et al. (in prep.)

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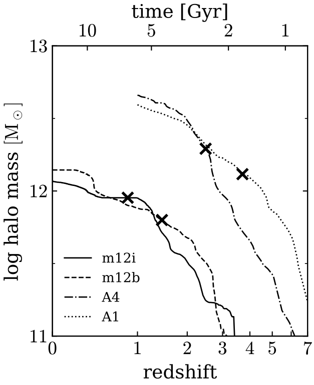
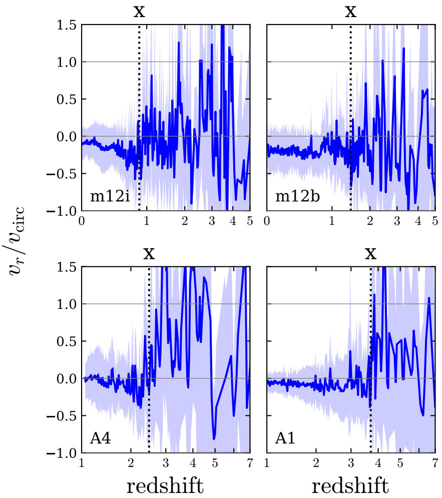
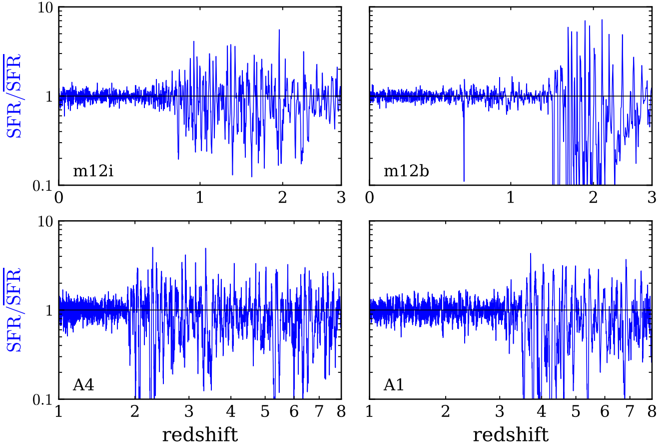




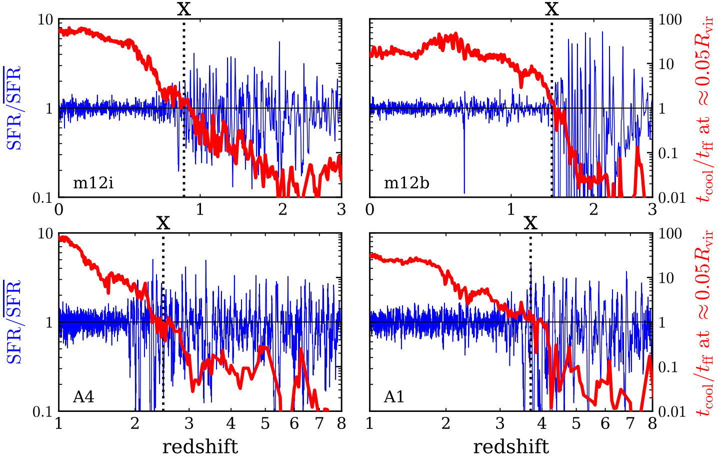
Stern et al. (in prep.)

Accretion mode versus the Star Formation Rate



Stern et al. (in prep.), SFRs see Faucher-Giguère (2018)

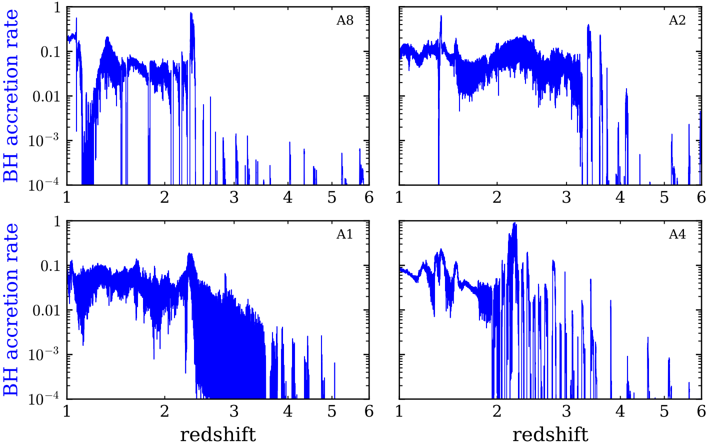
Accretion mode versus the Star Formation Rate



Stern et al. (in prep.), SFRs see Faucher-Giguère (2018)

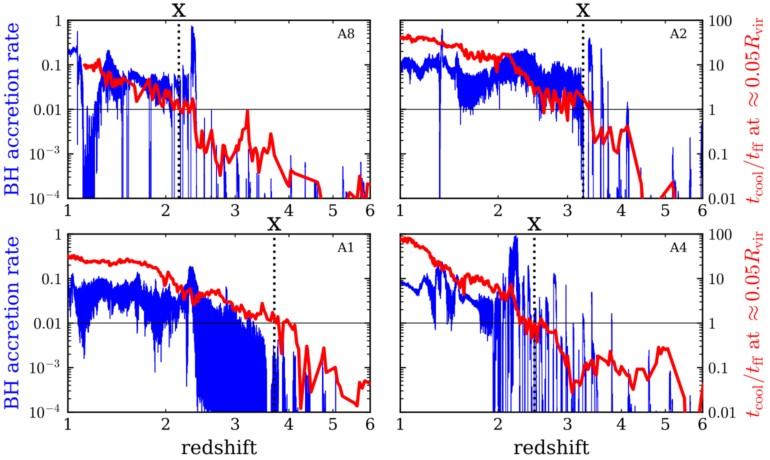
Transition in accretion mode coincides with transition to steady SFR

Accretion mode versus Black Hole Growth



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

Accretion mode versus Black Hole Growth



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

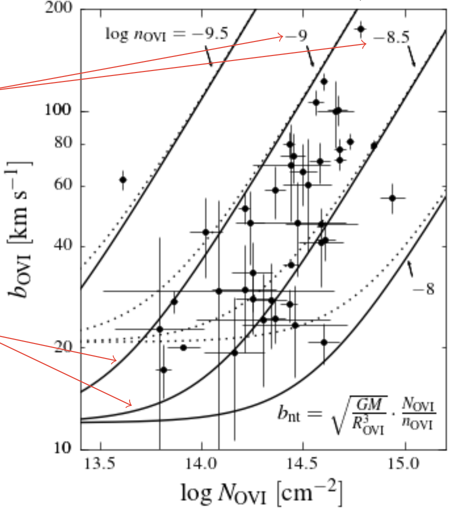
Transition in accretion mode coincides with significant BH growth

Kinematics of free-fall in UV absorbers

OVI densities suggested by line ratios

predicted velocity shear in free-falling gas for different OVI densities

Stern+18, obs' from COS-Halos (SF galaxies)



O VI *widths consistent with free-falling gas*

Summary: Two Accretion Modes onto $\sim L^*$ Galaxies

1. The nature of accretion determined by conditions at *galaxy outskirts*

2. Transition in accretion onto galaxies in *FIRE* coincides with
    - cessation of SF-driven outflows
    - transition from *bursty* to *steady* star formation
    - onset of BH growth

3. O VI widths consistent with *free-falling outer CGM around SF galaxies*