The Growth and Radiative Signatures of High Redshift Black Holes

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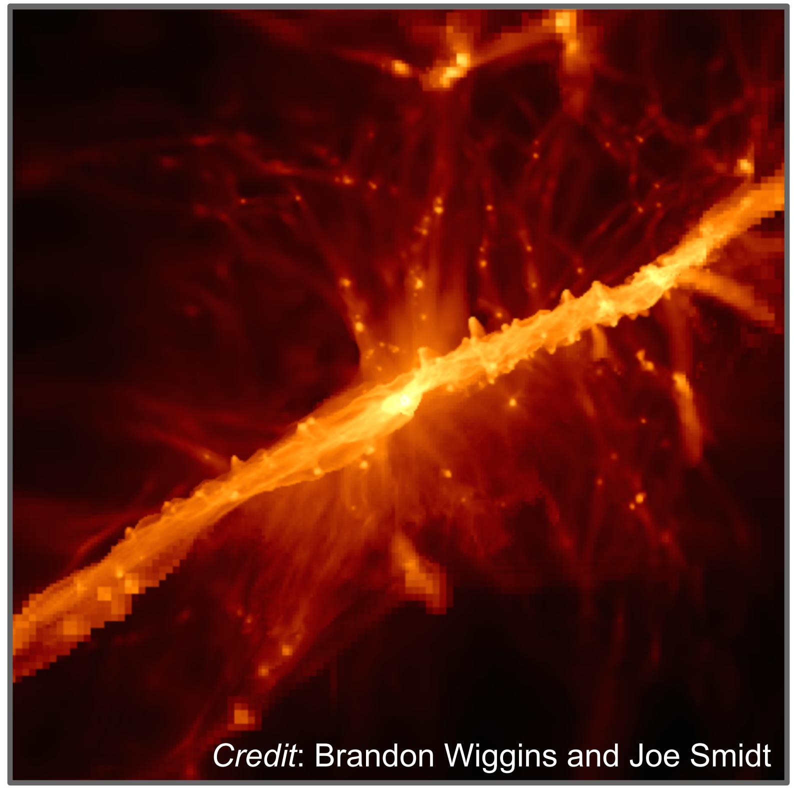

Credit: Brandon Wiggins and Joe Smidt

The Reionization Epoch

Aspen Center for Physics

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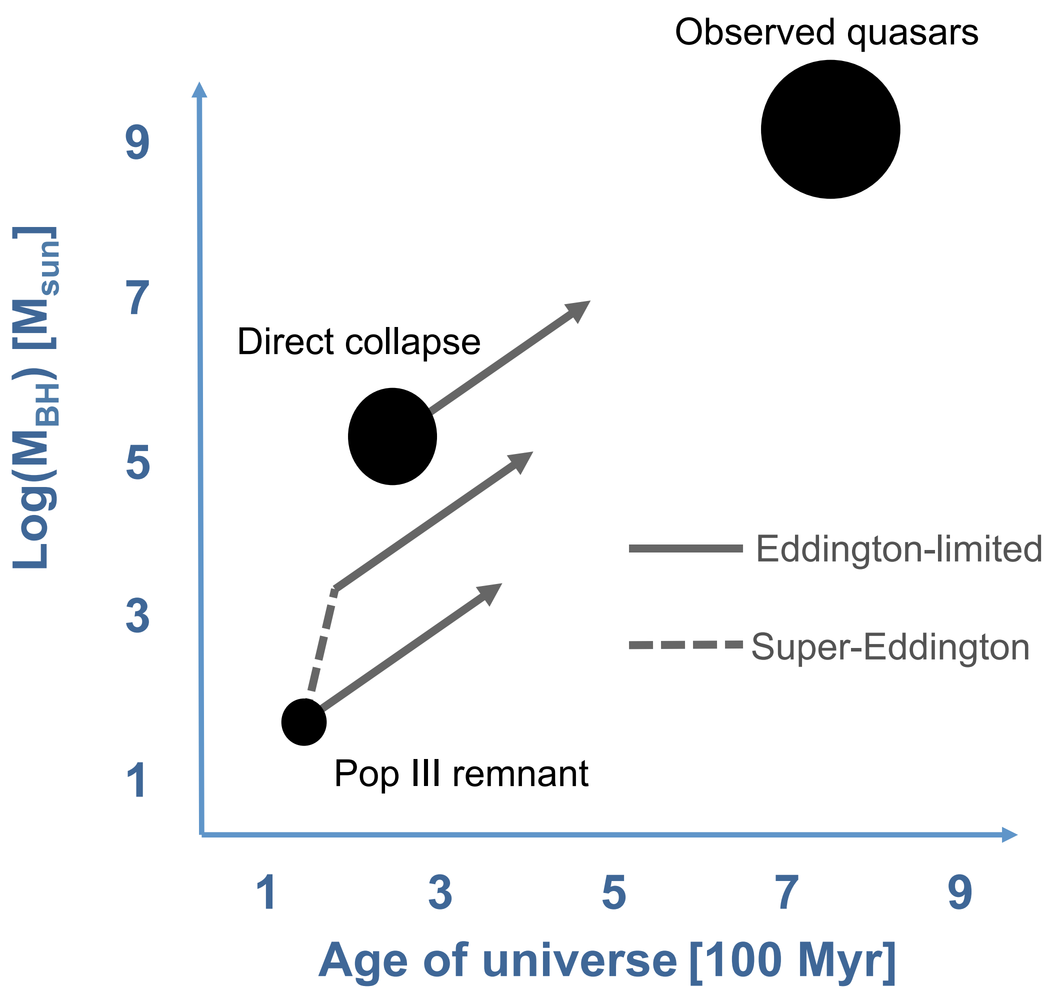
Formation and Growth of the First Black Holes



For reviews see Volonteri 2012; Haiman 2013; Johnson & Haardt (2016)

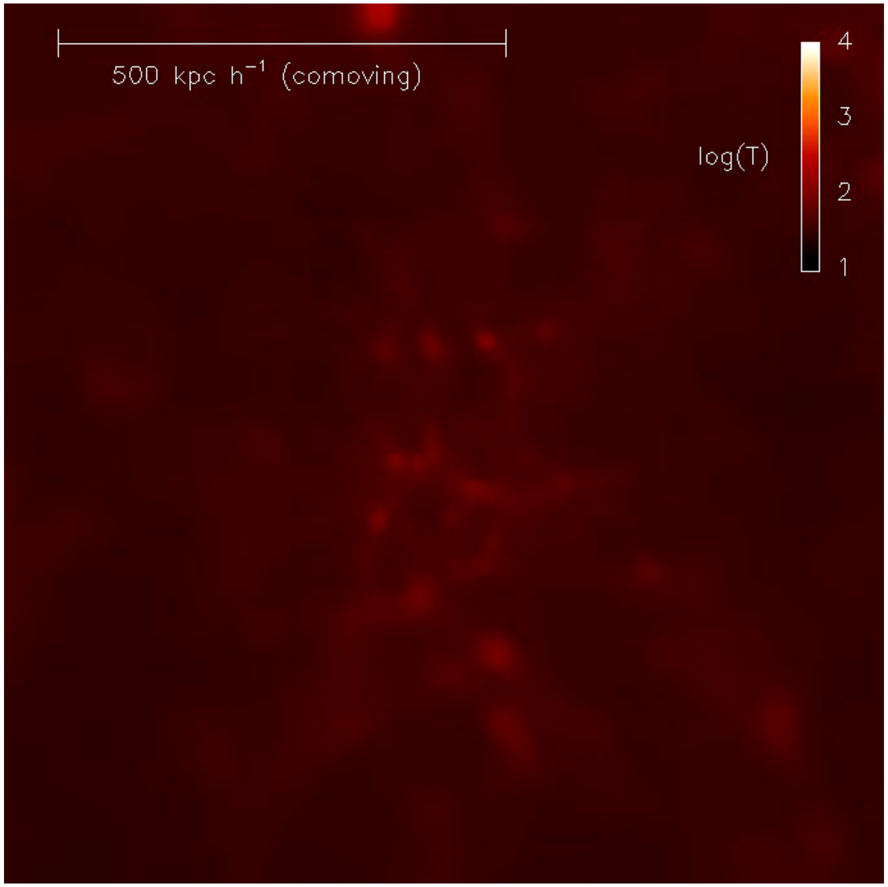
DCBH Formation from Hot Primordial Gas

- An elevated H_2-dissociating (LW) radiation field suppresses cooling of the primordial gas (e.g. Dijkstra et al. 2008; Agarwal et al. 2012; Sugimura et al. 2014; Visbal et al. 2014; Inayoshi et al. 2015)

- Gas cools to only ~ 10^4 K by collisional excitation of hydrogen (e.g. Bromm & Loeb 2003; Wise et al. 2008; Regan & Haehnelt 2009; Shang et al. 2010; Latif et al. 2013; Becerra et al. 2015; Choi et al. 2015)

- *Gas collapses and accretes onto central supermassive star at ~ 0.1 – 1 M_{sun} yr^{-1}* (e.g. Begelman 2010; Johnson et al. 2012; Schleicher et al. 2013; Hosokawa et al. 2013; Sakurai et al. 2015; Pacucci & Ferrara 2015)

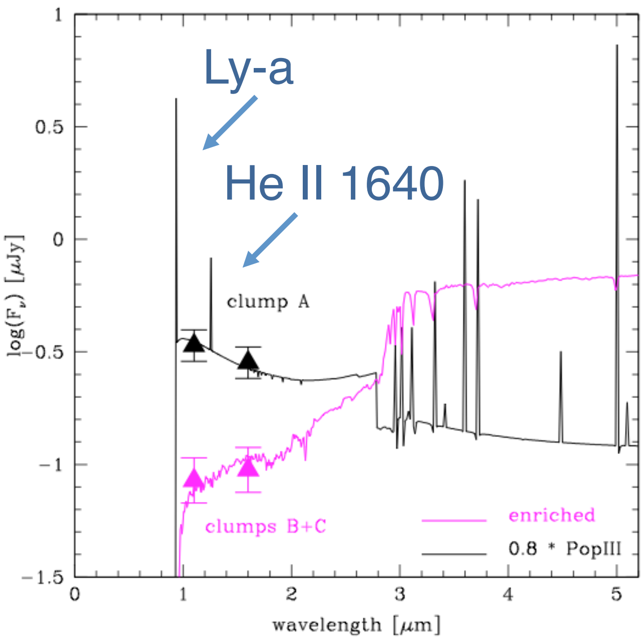
Gas temperature



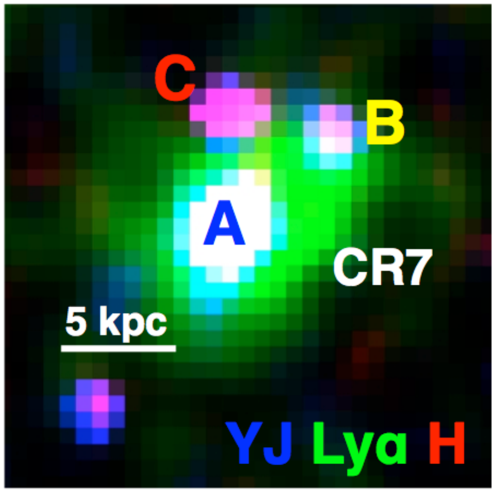
Johnson, Khochfar, Durier & Greif (2011)

A Candidate Direct Collapse Black Hole in CR7

- The most luminous Ly-a emitter at z > 6 (Sobral et al. 2015)
- No metal lines detected – primordial?
- Luminosity of He II 1640 angstrom line and proximity of neighboring galaxies suggest power supplied by an accreting DCBH (Agarwal et al. 2015; Pallottini et al. 2015; Hartwig et al. 2015; Dijkstra et al. 2016; Smith et al. 2016)



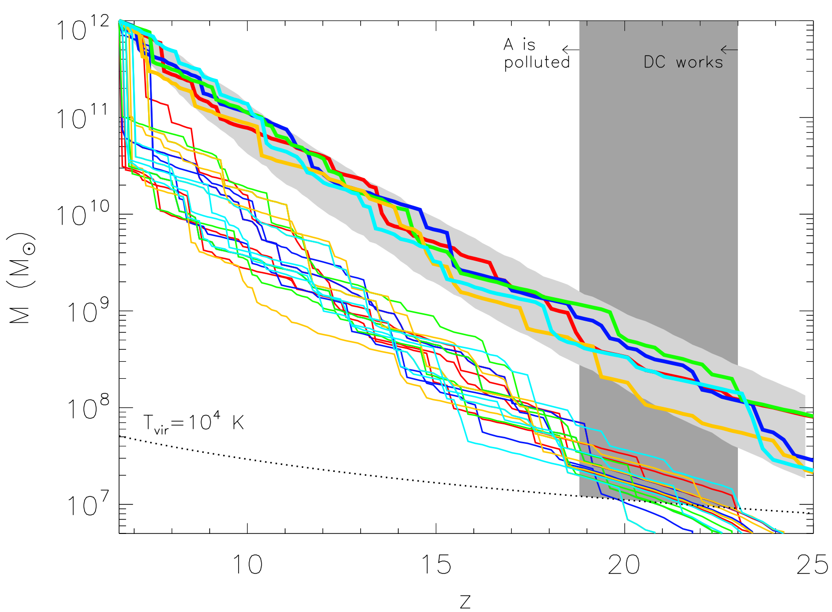
H2-dissociating radiation from sources B and C led to formation of DCBH in source A, at $z > 10$

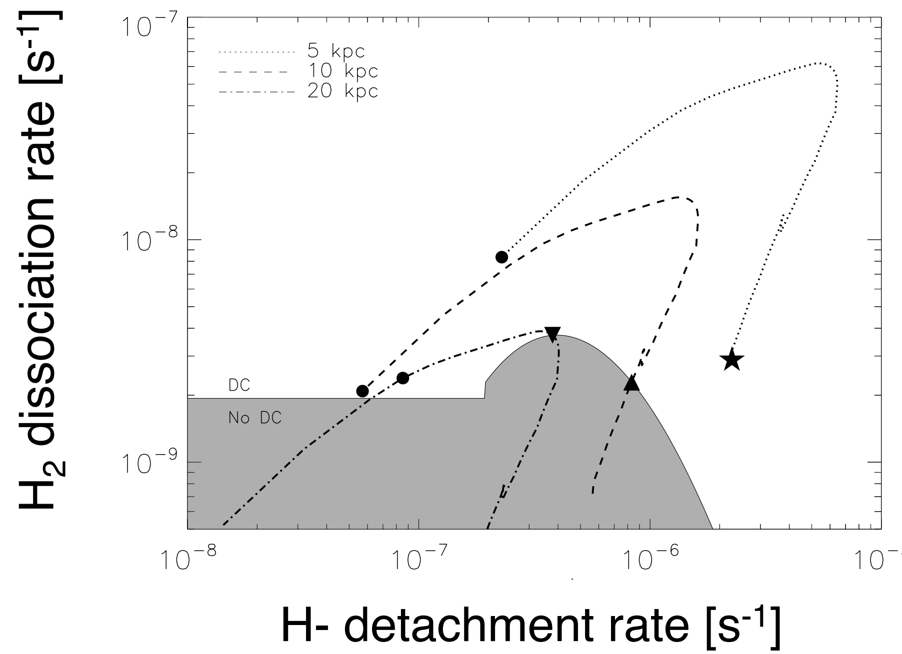


Sobral et al. (2015)

Modeling the Origin of the DCBH in CR7

- Modeling of the star formation history in clumps B and C suggests that the LW flux is high enough for DCBH formation in clump A, if their separation is < 20 kpc





- DCBH host halo merges with nearby galaxy-hosting halo just prior to z = 6.6

Agarwal, Johnson, et al. (2015)

Cosmological Simulations of CR7 as an Active Black Hole

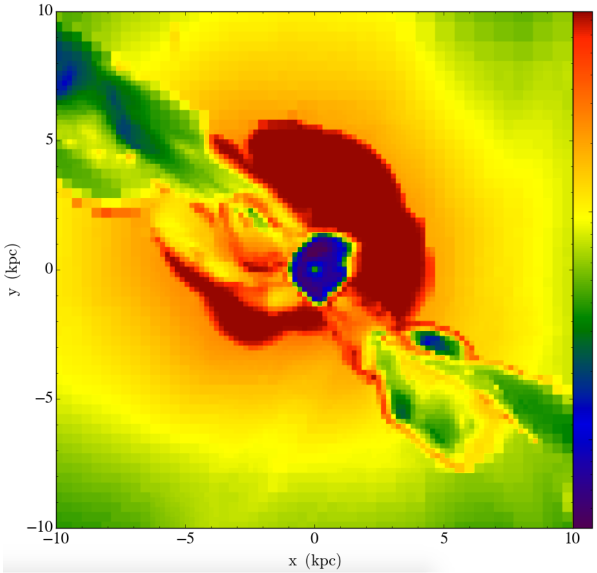
- Our *Enzo* simulations start at z = 15, when halo is seeded at atomic cooling threshold; ends at redshift of CR7, z = 6.6
- Here we focus on an isolated ~ 3 x 10^{10} Msun halo (e.g. Agarwal et al. 2015), neglecting the neighboring clumps B and C that produce LW radiation
- We account for a background LW radiation field with $J_{21} = 10^4$ as a simplification

Credit: Joe Smidt

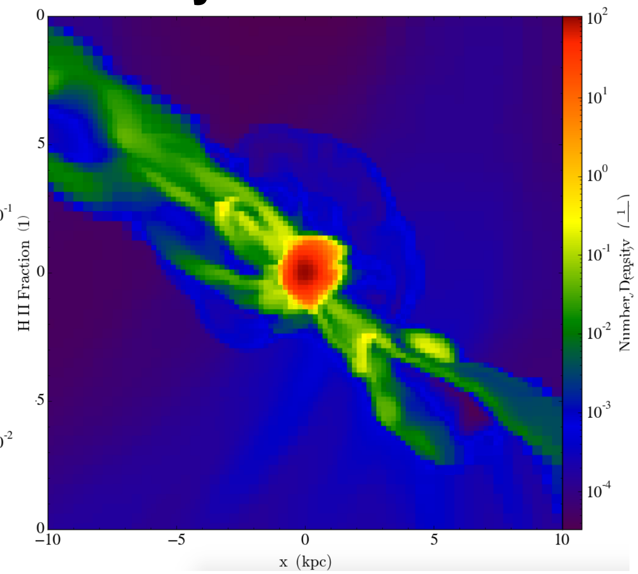
Smidt, Wiggins & Johnson (submitted)

Modeling X-ray Feedback from the BH in CR7

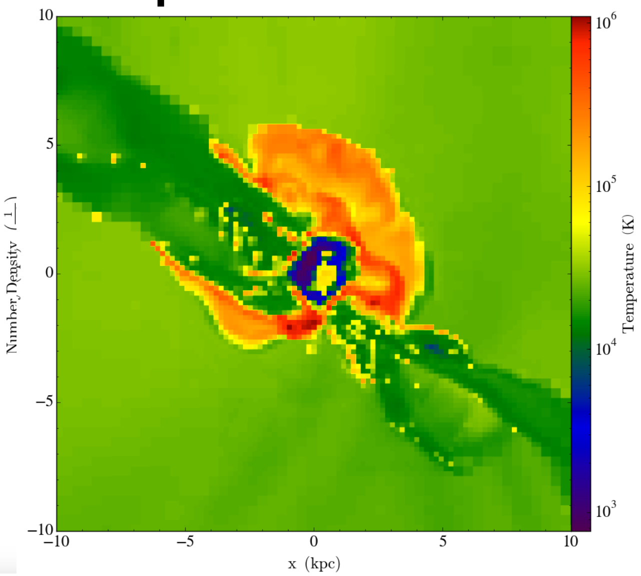
Ionized fraction



Density



Temperature



Properties of the black hole at z = 6.6:

$M_{BH} \sim 2 \times 10^7$ Msun

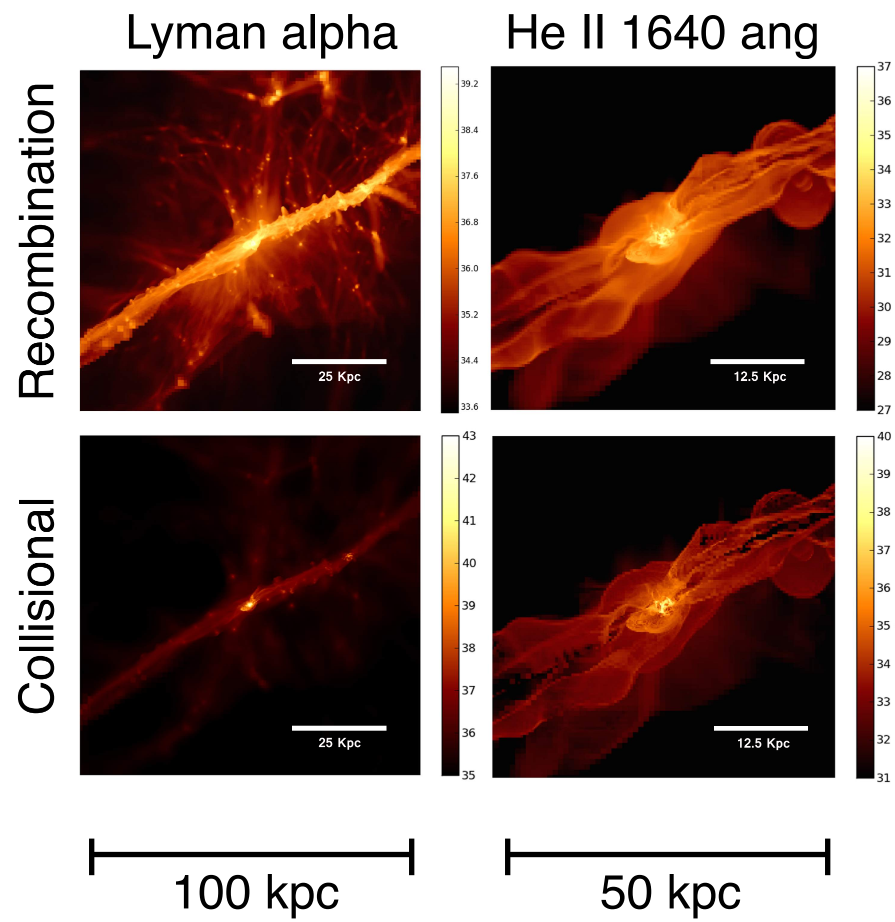
$dM_{BH}/dt \sim 0.16$ Msun yr $^{-1}$ (0.25 Eddington)

Smidt, Wiggins & Johnson (submitted)

Modeling the Nebular Emission from CR7

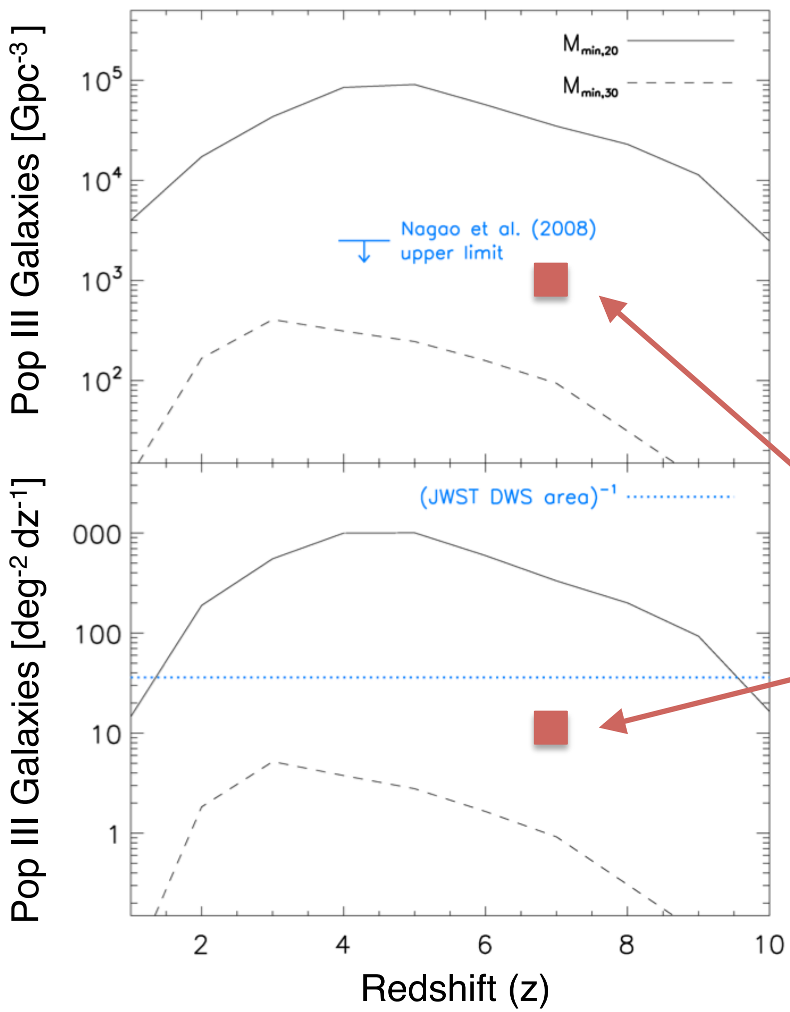
- UV radiation ionizes the gas, which then emits via recombination
- X-rays heat the gas, but only partially ionize, leading to emission from collisionally-excited species (see also Smith et al. 2016)
- Slightly low luminosities suggest that the halo hosting clump A in CR7 may be > 3 x 10^{10} Msun

	Obs	Sim
Lyα [10^{43} erg s^{-1}]	> 8.3	50
He II 1640 [10^{43} erg s^{-1}]	2	2.3
Width He II 1640 [km s^{-1}]	130	210
Width Lyman-α [km s^{-1}]	260	270



Smidt, Wiggins & Johnson (submitted)

Population III Stars: An Alternative Explanation



Johnson (2010)

- Bright Population III galaxies may form in ~ 10^9 Msun halos at modest redshifts, due to photoheating of IGM during reionization (Johnson 2010; see also Trenti et al. 2009 on LW feedback)

Revisited: Visbal et al. (2016) have now applied this theory to model CR7, finding a similar cosmic abundance of Pop III-powered galaxies

*A star formation efficiency of ~ 0.07, assuming a very top-heavy IMF, is required

Summary

- There is a defensible case that the Lyman-α emitter CR7 is powered by accretion onto a direct collapse BH
- Cosmological radiation hydrodynamic simulations support more idealized modeling efforts in this interpretation
- Modeling objects like CR7 is important in order to be ready for many more such observations in coming years (JWST)
- *See Dan Whalen's talk (next) for another application of our simulation technique to the most massive high-z BHs*