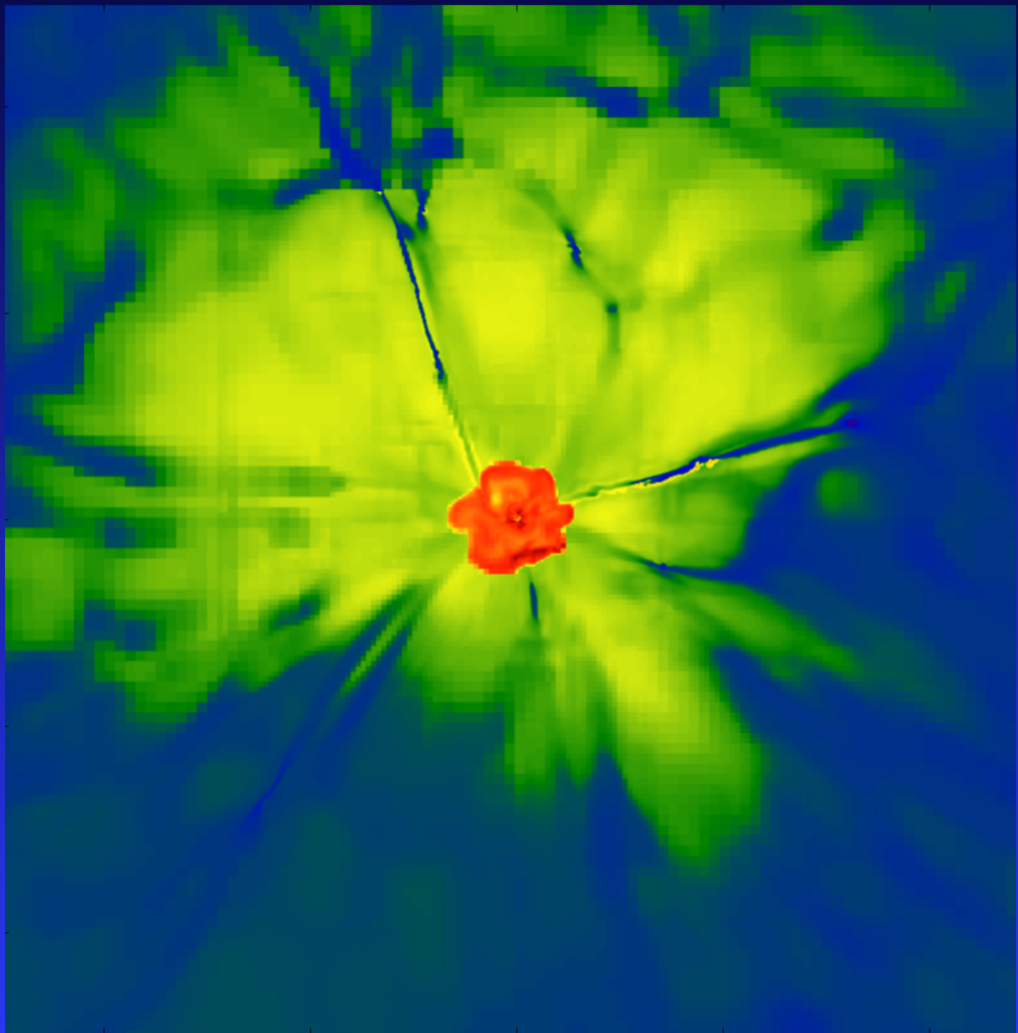
How Supermassive Black Holes Form by z ~ 7



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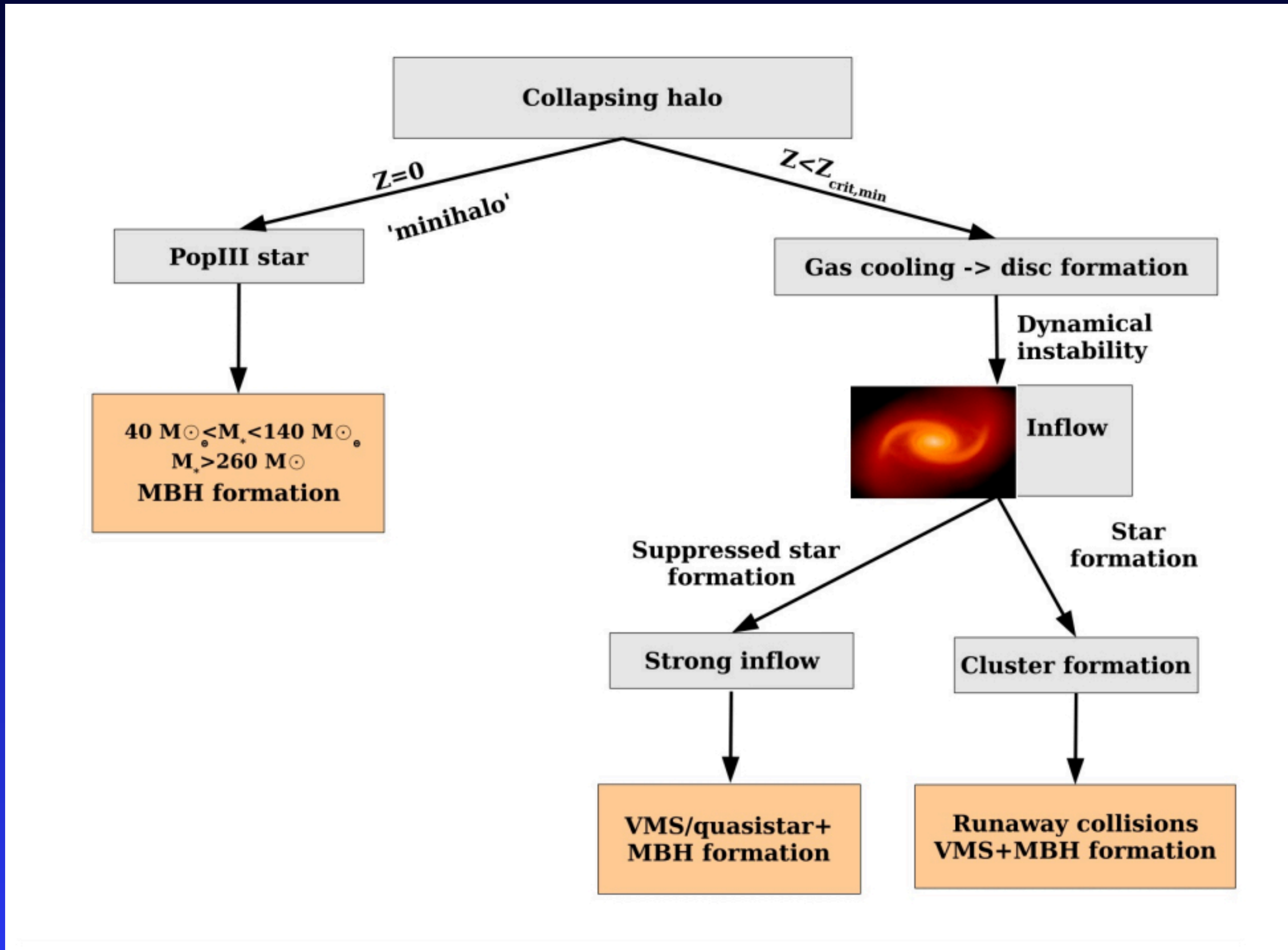
Lawrence Berkeley National Laboratory, Sept 1, 2016

Massive Quasars at z > 6

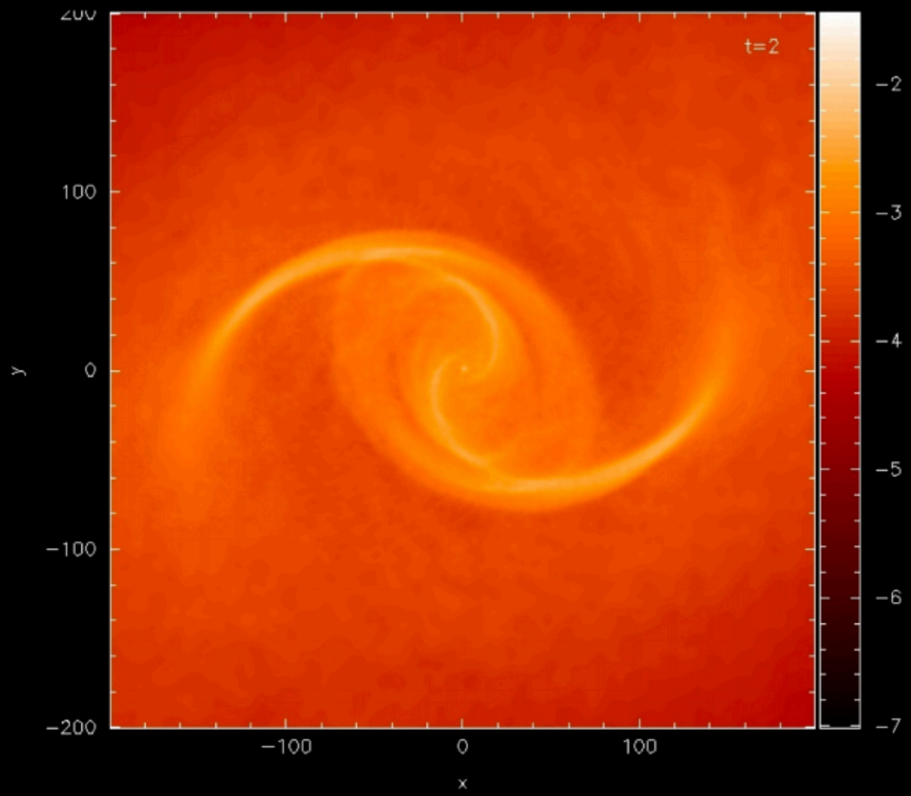
- over 100 quasars have now been found at $z > 6$
- ULAS J1120+0641 is a 2 billion $M_{\odot}$ SMBH at $z = 7.1$ (Mortlock et al. 2011, Nature, 474, 616)
- SDSS J010013.02+280225.8 is a 12 billion $M_{\odot}$ BH at $z = 6.3$ (Wu et al. 2015, Nature, 518, 512)
- how do BHs this massive form 770 Myr after the Big Bang?

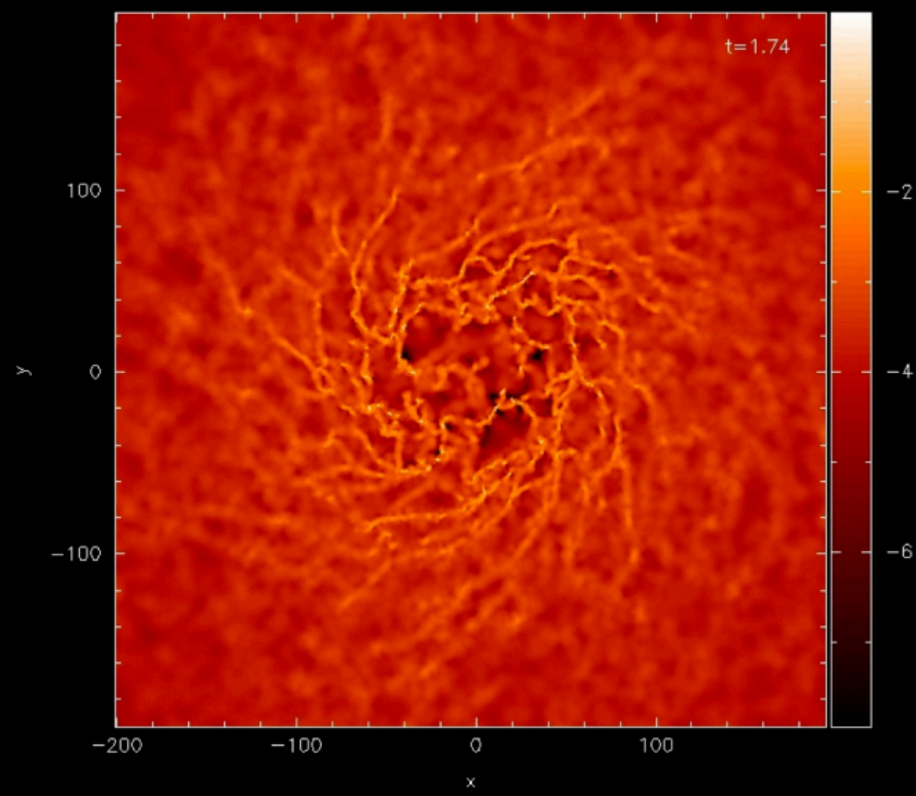
SMBH Seed Formation Pathways



from Volonteri, ARAA, 2010, 18, 279

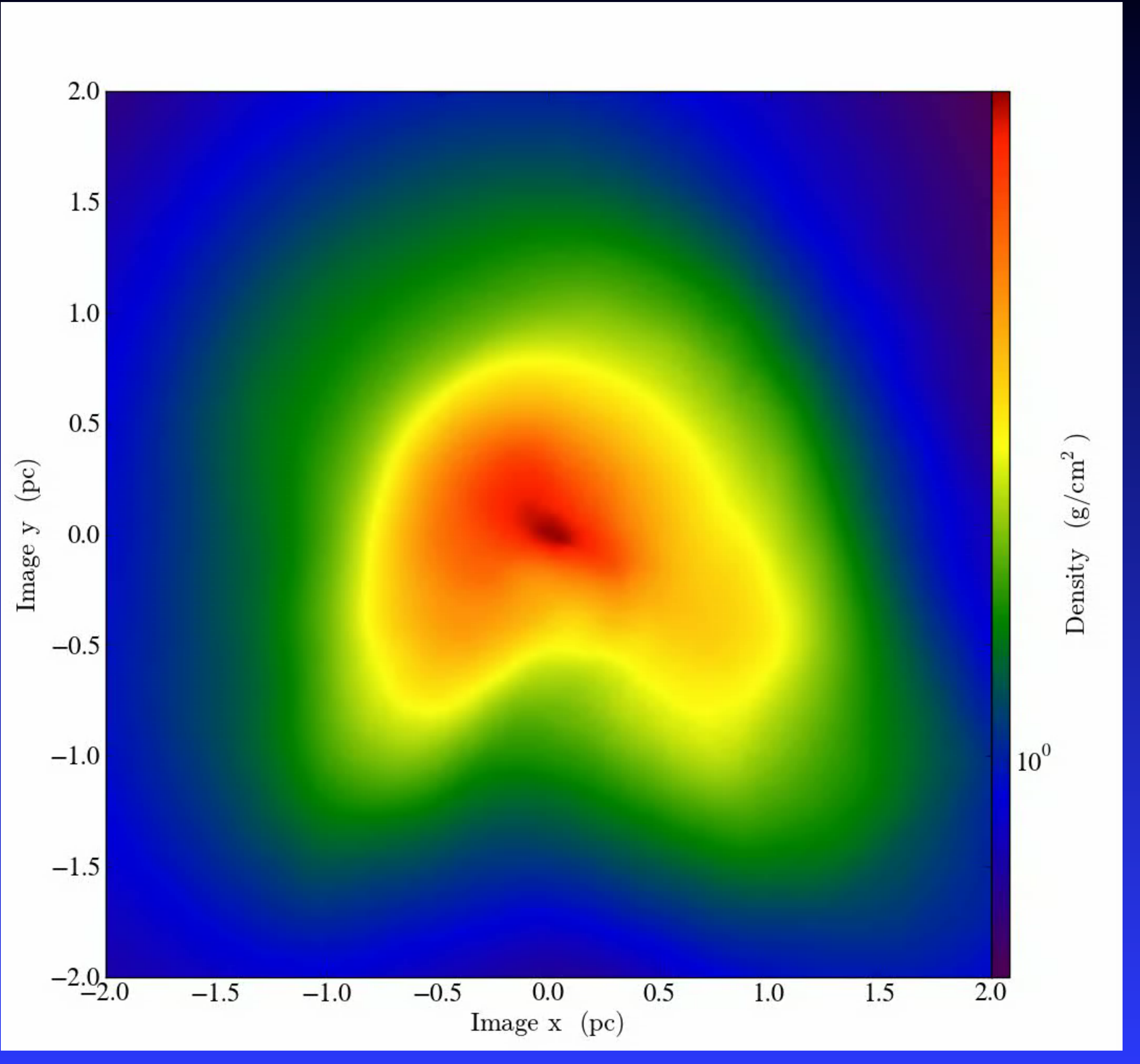
Direct Collapse Scenarios
$z \sim 15$ - 20





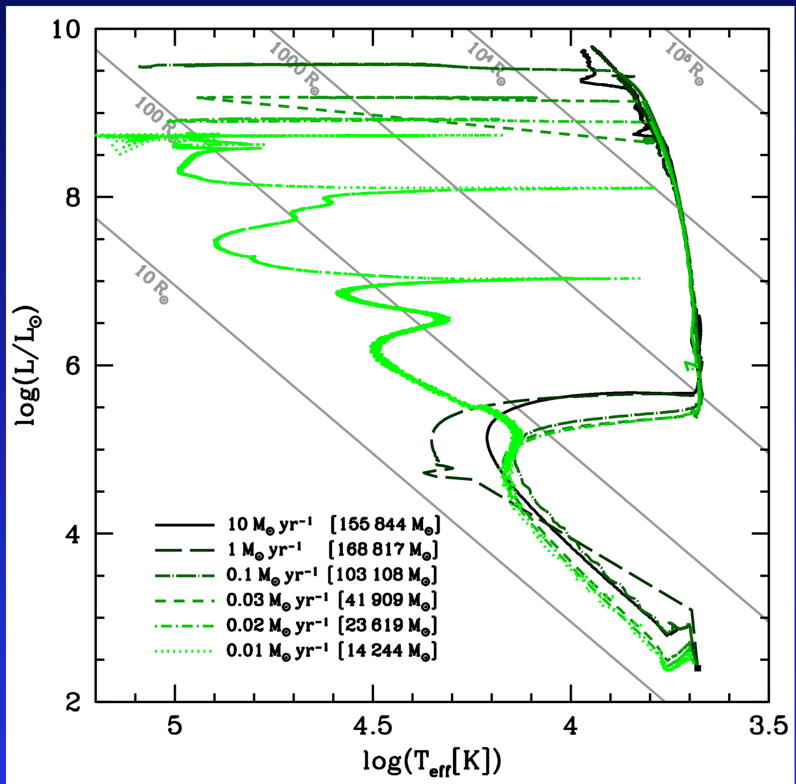
$Z \sim 0$

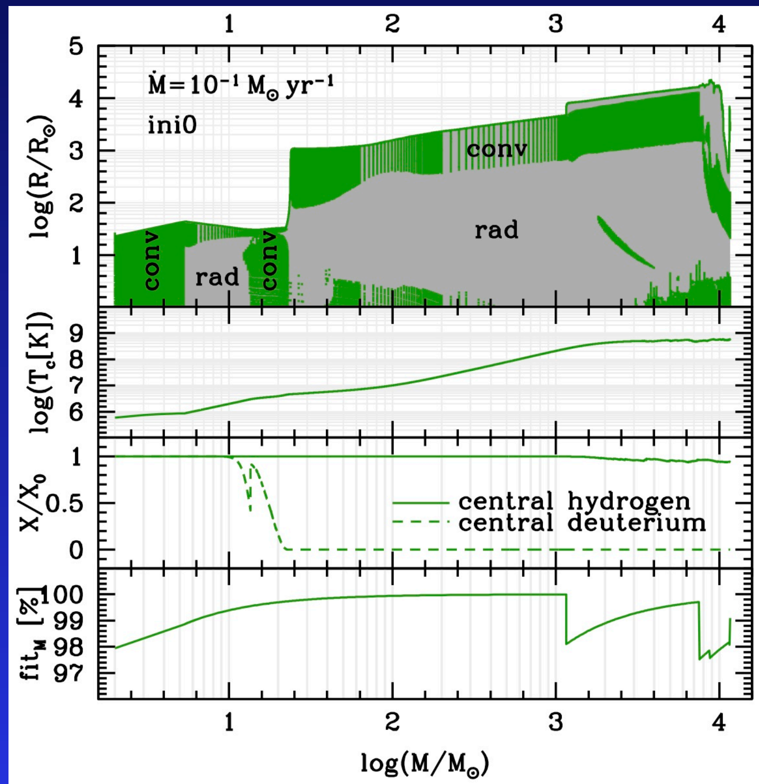
$Z \sim 10^{-4}\, Z_{\odot}$



2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
Image y (pc)
−2.0
−1.5
−1.0
−0.5
0.0
0.5
1.0
1.5
2.0
Image x (pc)
10^0
Density (g/cm^2)

Supermassive Pop III Stellar Evolution

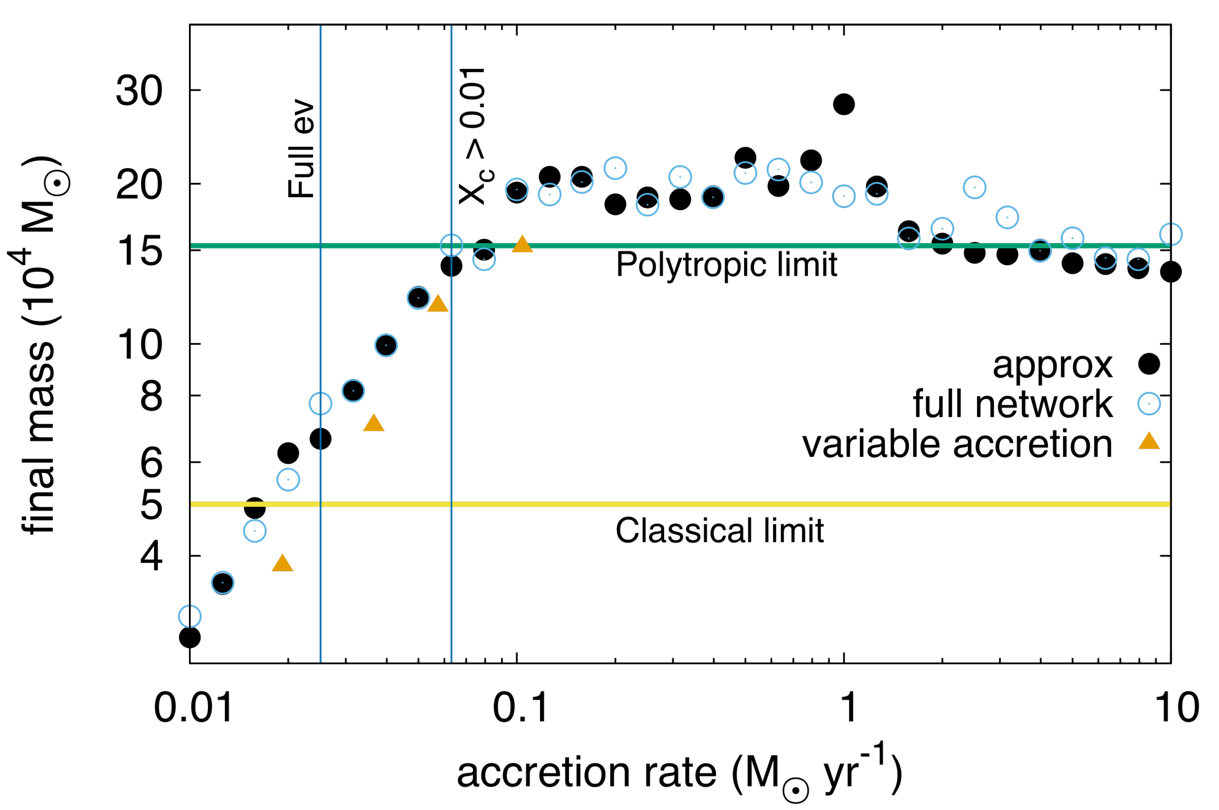




Supermassive Pop III Stellar Mass at Collapse

Woods + DJW+ 2016 in prep

Hammerle + DJW+ 2016 in prep

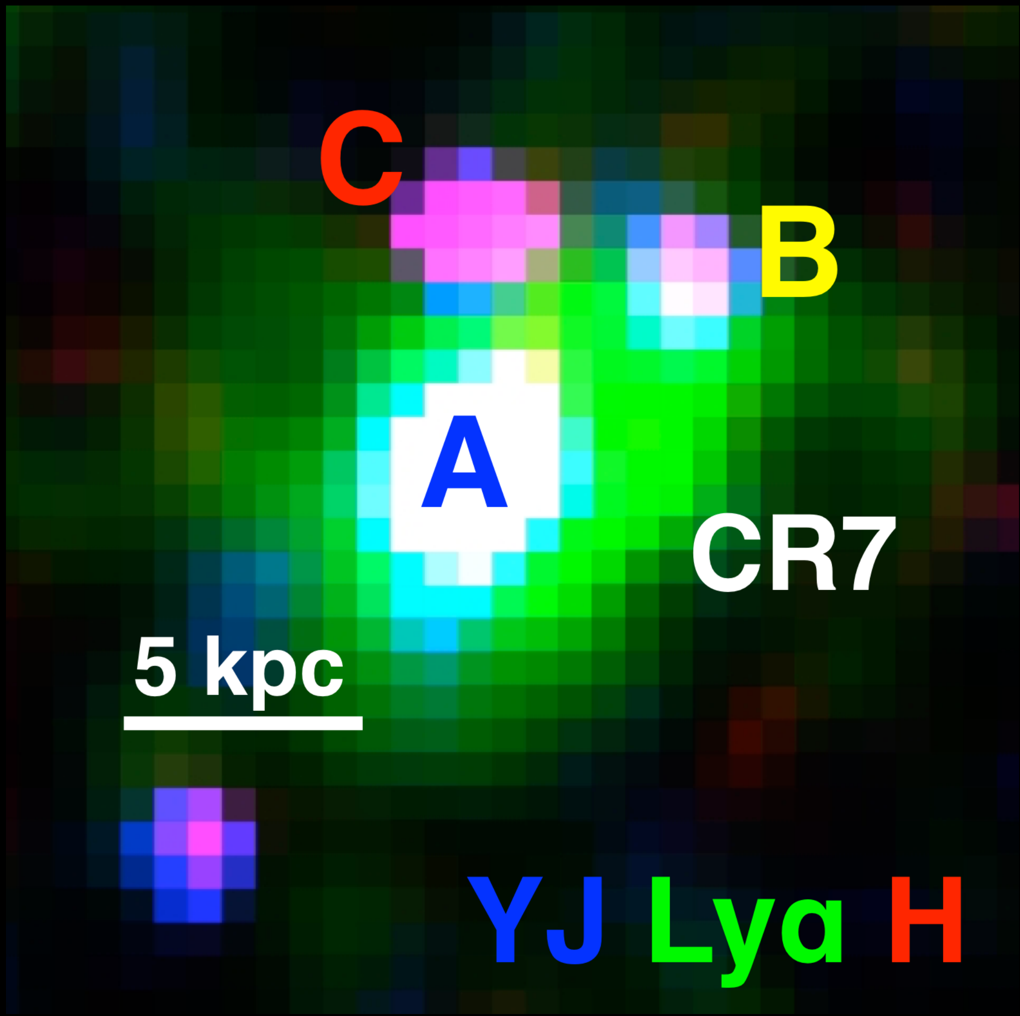


The Case For SMBH Seed Formation by Direct Collapse for z > 6 quasars

- Pop III BHs are "born starving" (Whalen et al. 2004; Alvarez et al. 2006; Abel, Wise & Bryan 2007)

- once accretion begins, low-mass halos have gravity potentials that are too shallow to retain gas that is heated by x-rays (e.g., Whalen et al. 2004)

- low-mass Pop III BHs are often ejected from their host halos, and thus their fuel supply (Whalen & Fryer 2012, ApJL, 756, 19

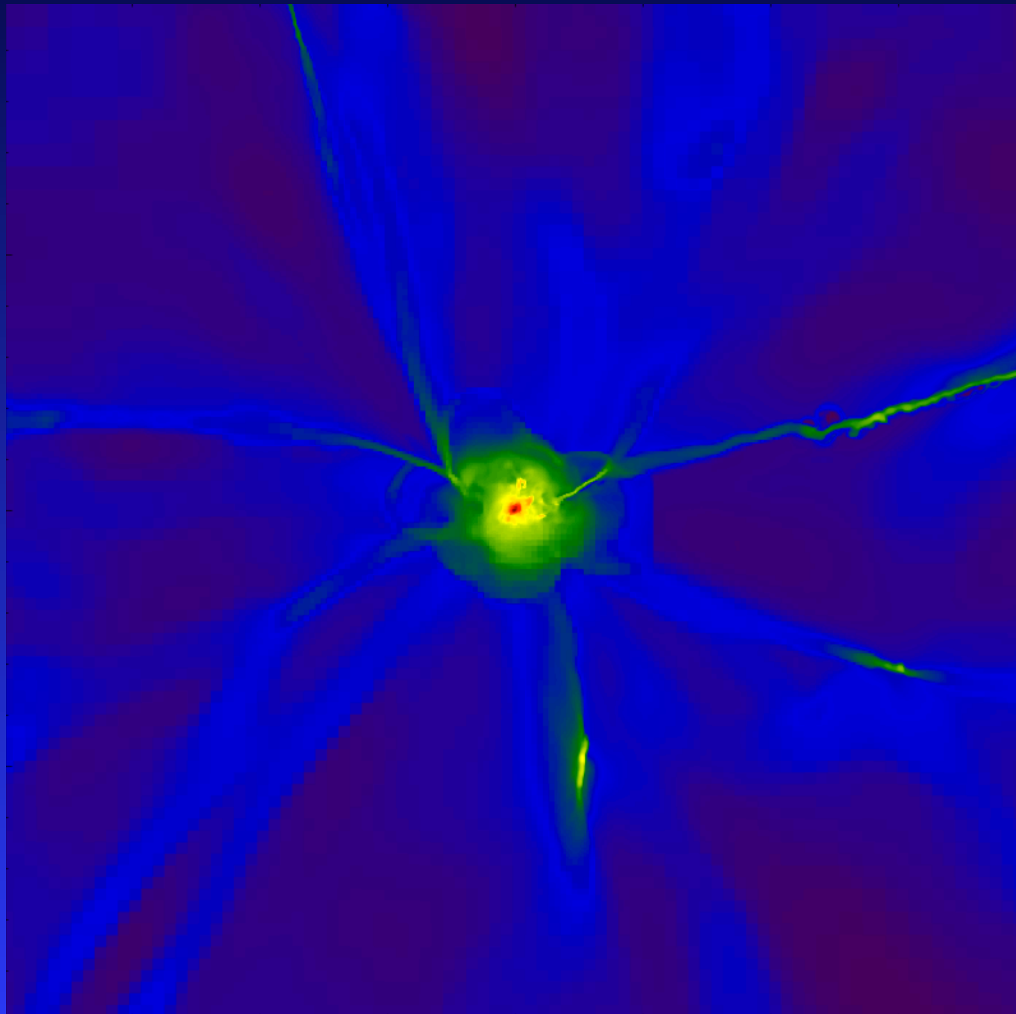


DCBH Candidate: CR7

Sobral et al. 2015, ApJ, 808, 139

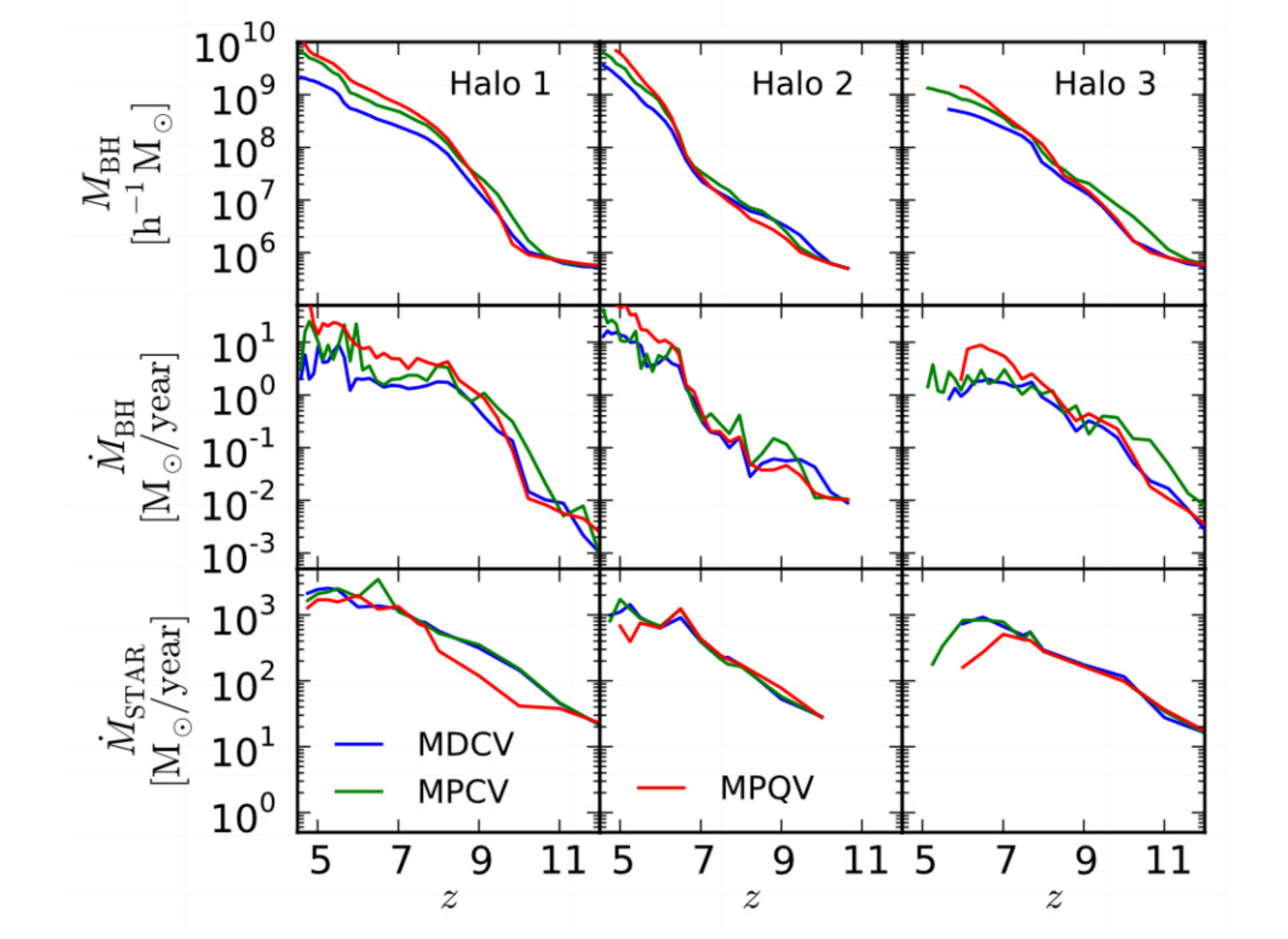
Cold Flows are also Key to Formation of the First Quasars

(e.g. Di Matteo, DeGraf et al. 2012 ApJ, 745, L29)



SMBH Growth with Thermal Feedback in Massive Black

Feng et al. 2014, MNRAS, 440, 1865

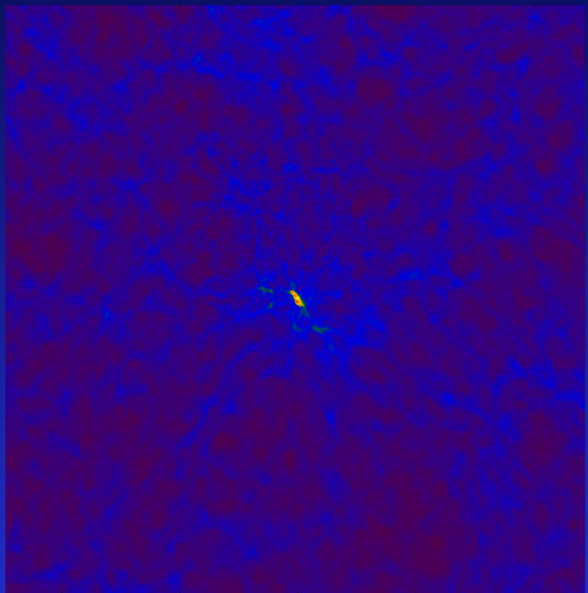


Enzo Supermassive Black Hole Formation Simulations

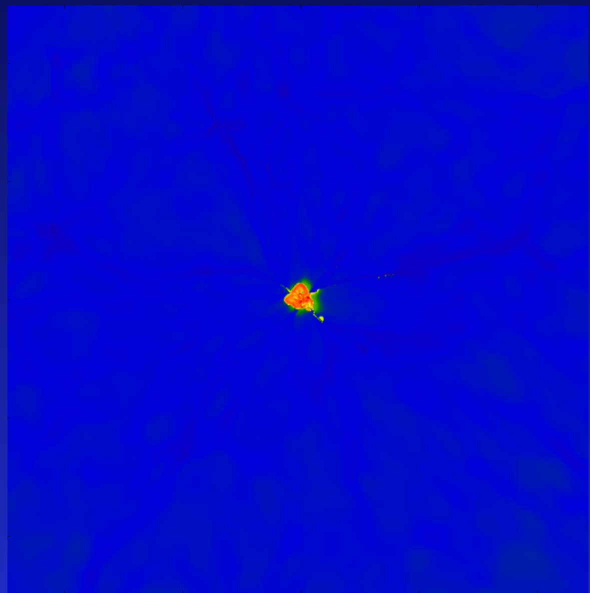
Smidt, DJW et al. 2016 in prep

- 100 Mpc box, initialized at $z = 200$
- x-ray emission from a 10^5 seed in a 5×10^8 solar mass halo at $z \sim 19$
- prescription for AGN jet feedback is included (DeBuhr et al. 2010)
- single photon energy of 1 keV – adaptive raytracing photon transport with the MORAY radiation package
- 10 levels of refinement, resolution of 30 pc
- subgrid alpha disk model of accretion
- multiphase star formation feedback in host galaxy (rad + SN)

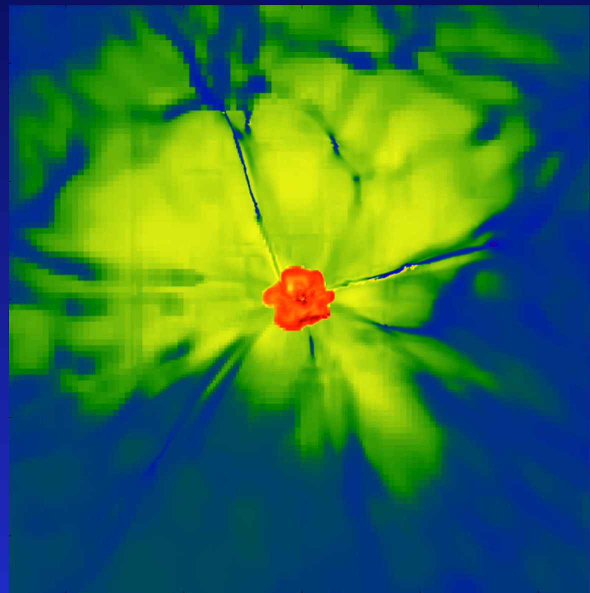
H II Region of the Quasar



z = 17

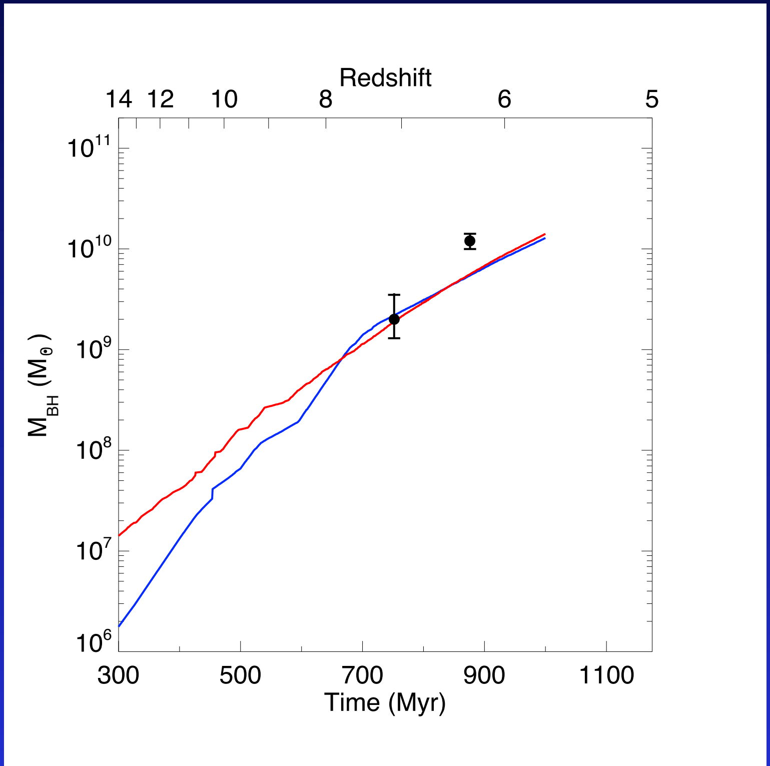


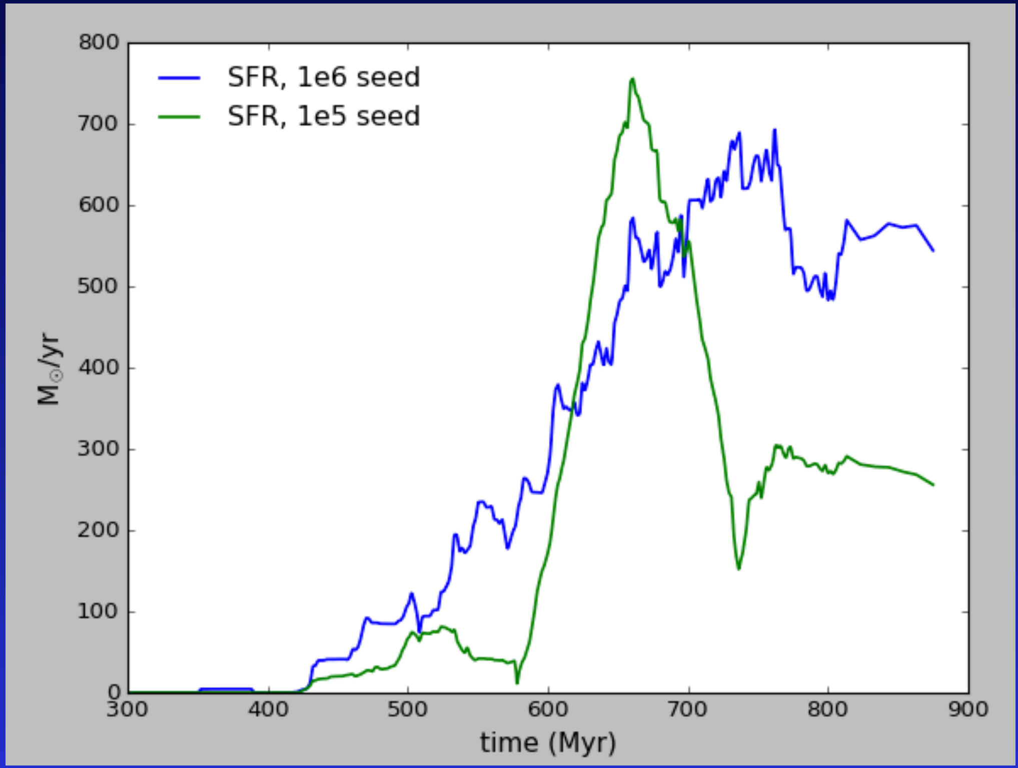
z = 9.5



z = 7

Primordial Star Formation Regulates SMBH Growth Rates from z > 10

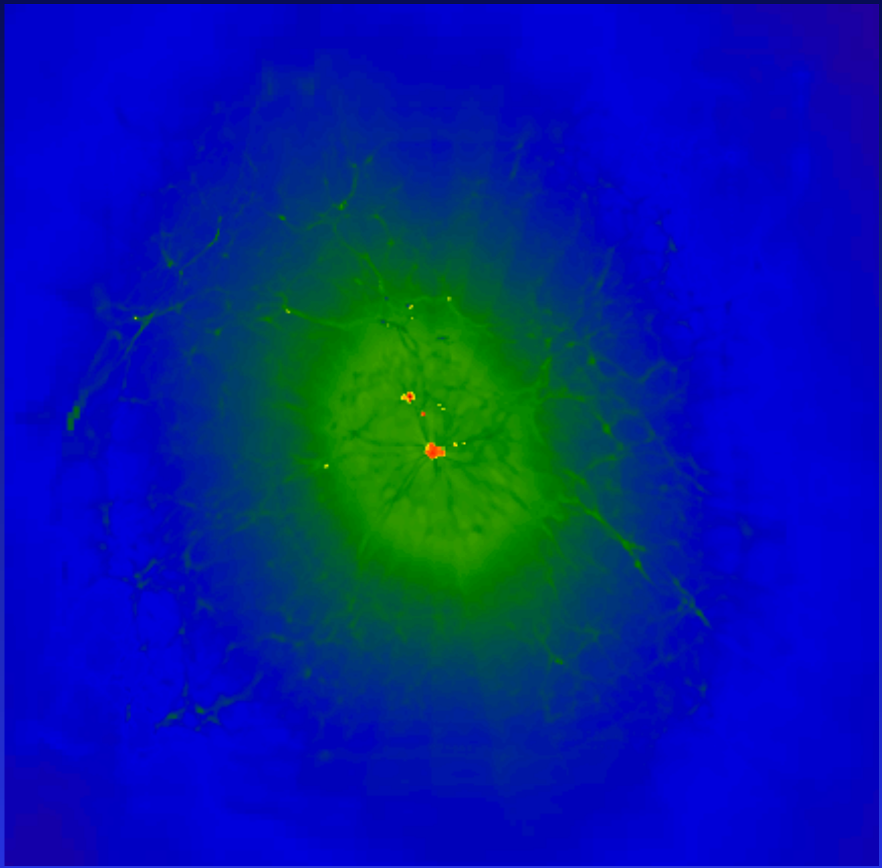


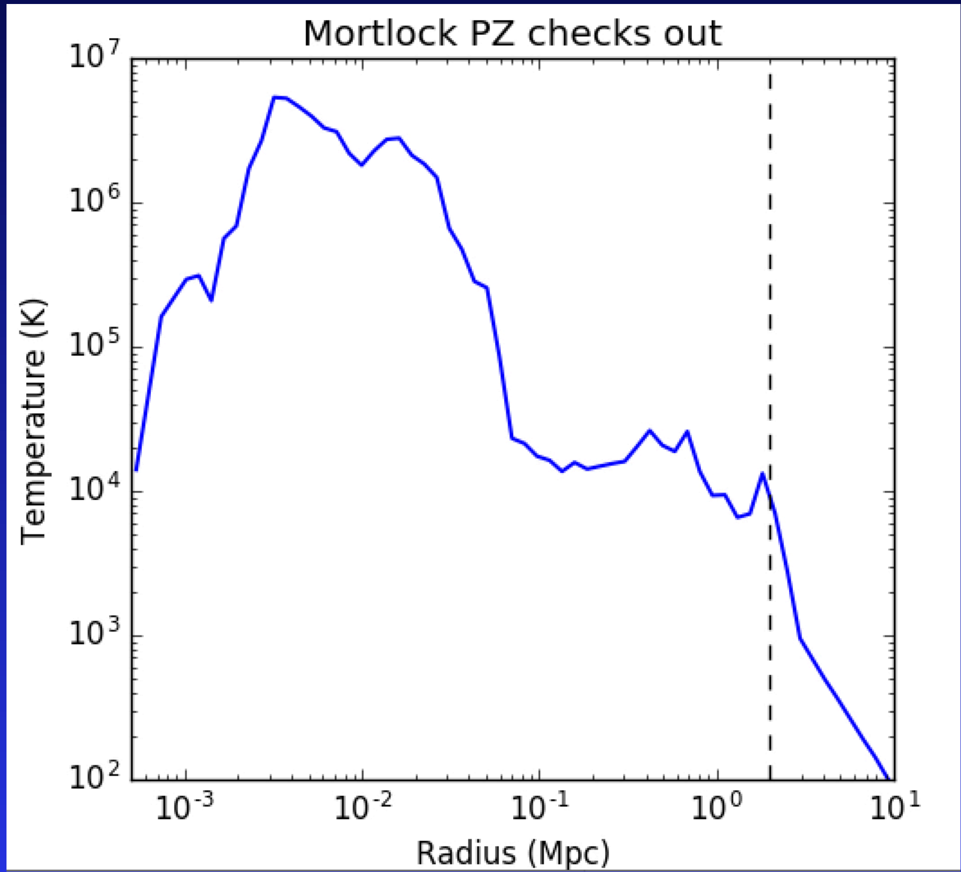


SMBH Mass

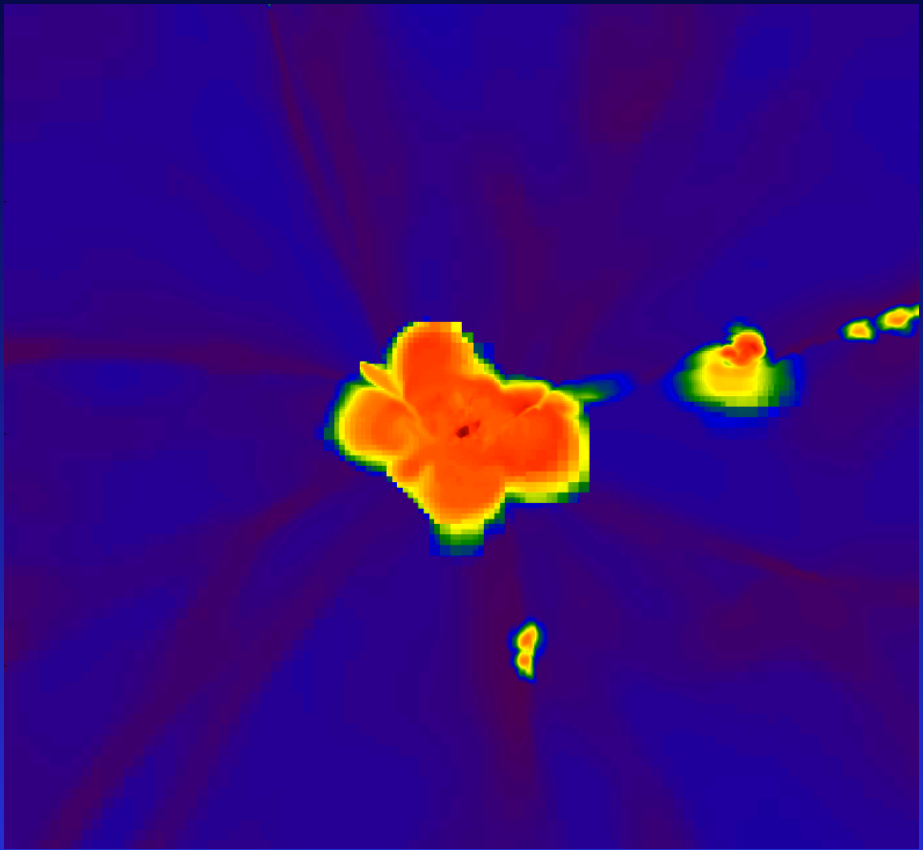
SFR ~ 250 $M_\odot$ in the host galaxy at z = 7.1, in agreement with obs (Barnett et al. 2015, A&A, 571, 33)

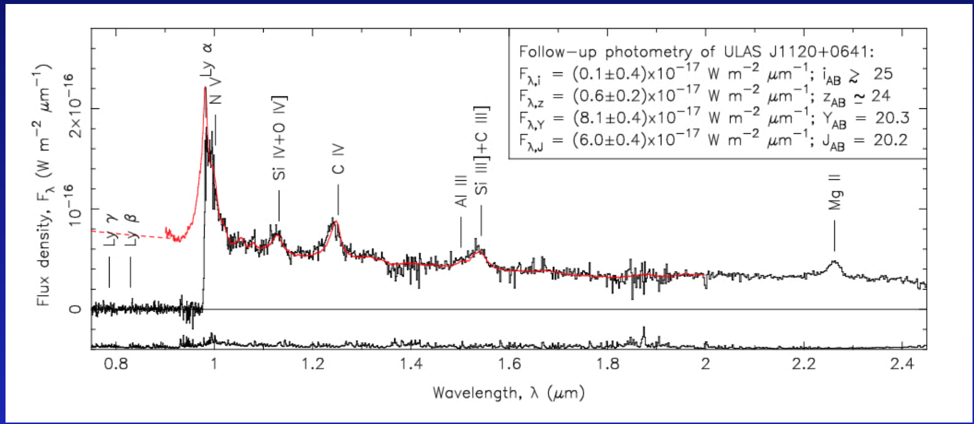
Mortlock Quasar Proximity Zone at z = 7.1





Metal and Dust Enrichment in the Host Galaxy





The metallicity in the host galaxy at z = 7.1 is approximately solar, in agreement with strong C lines (Dunlop 2013)

Conclusions

- x-ray feedback + SF rad / SN feedback can account for the existence of the Mortlock 2011 and Wu 2015 quasars
- Pop III BHs almost certainly cannot be the origin of these two quasars
- our prescription for SF feedback in the host galaxy produces SFRs and metallicities consistent with observations
- next step is to calculate realistic synthetic observables for the first quasars (NIR continuum, Ly-a, 21 cm)
- soon perform ensemble studies of large numbers of $5 < z < 15$ quasars to study the population at this epoch