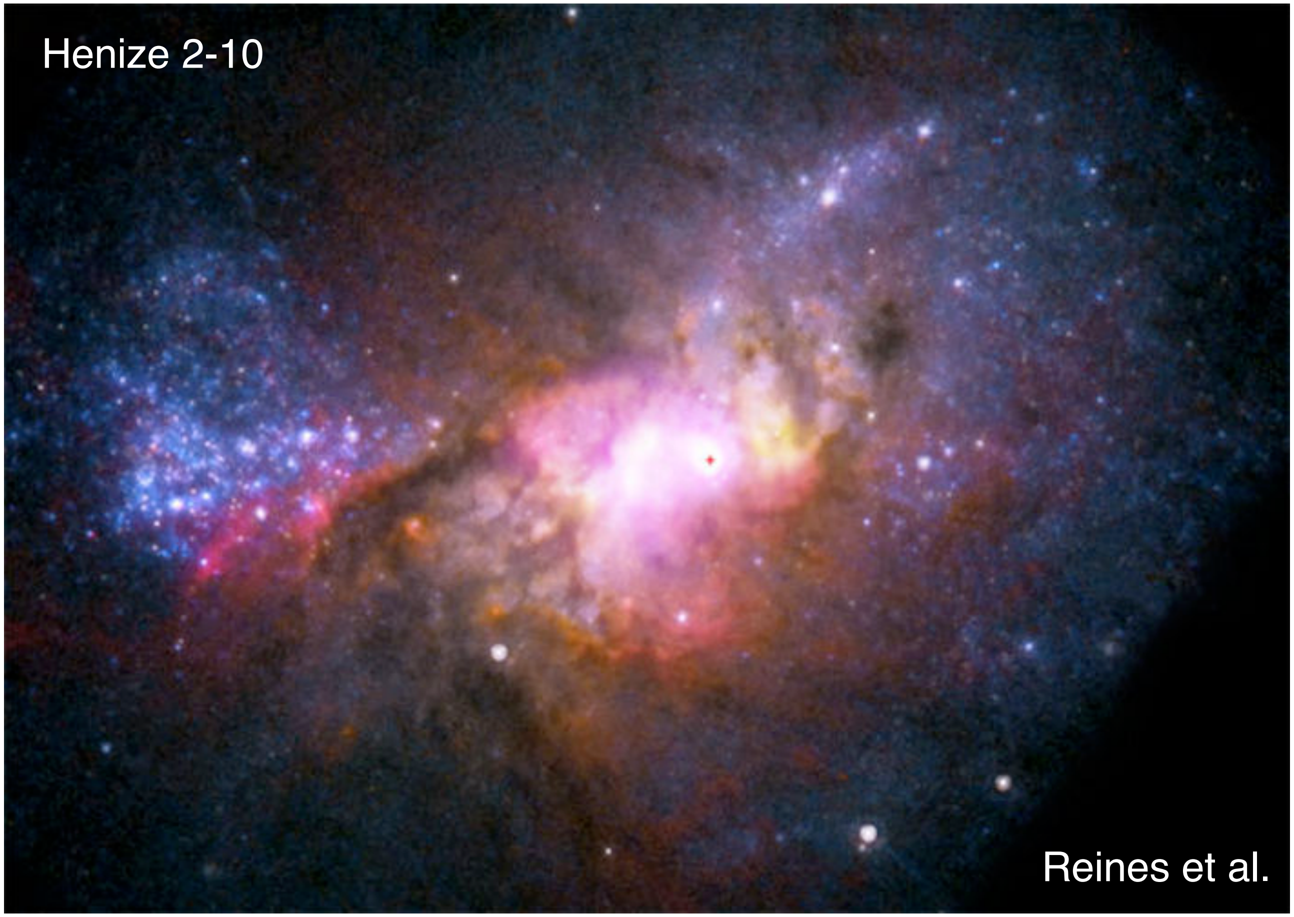
Sowing Black Hole Seeds



Kelly Holley-Bockelmann
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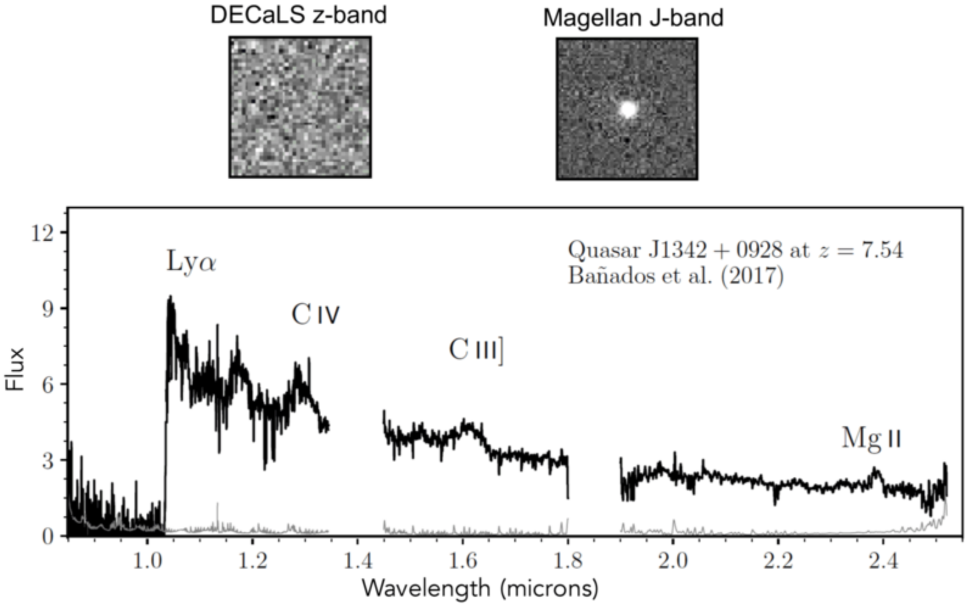
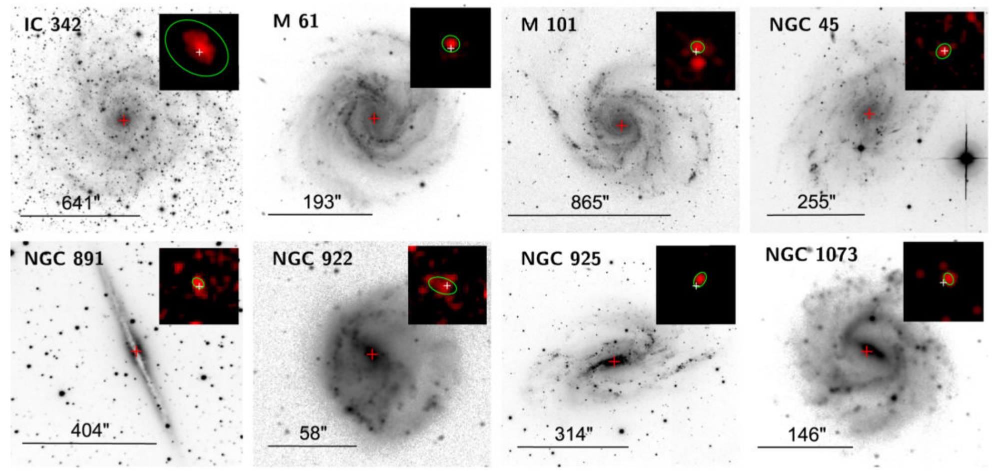
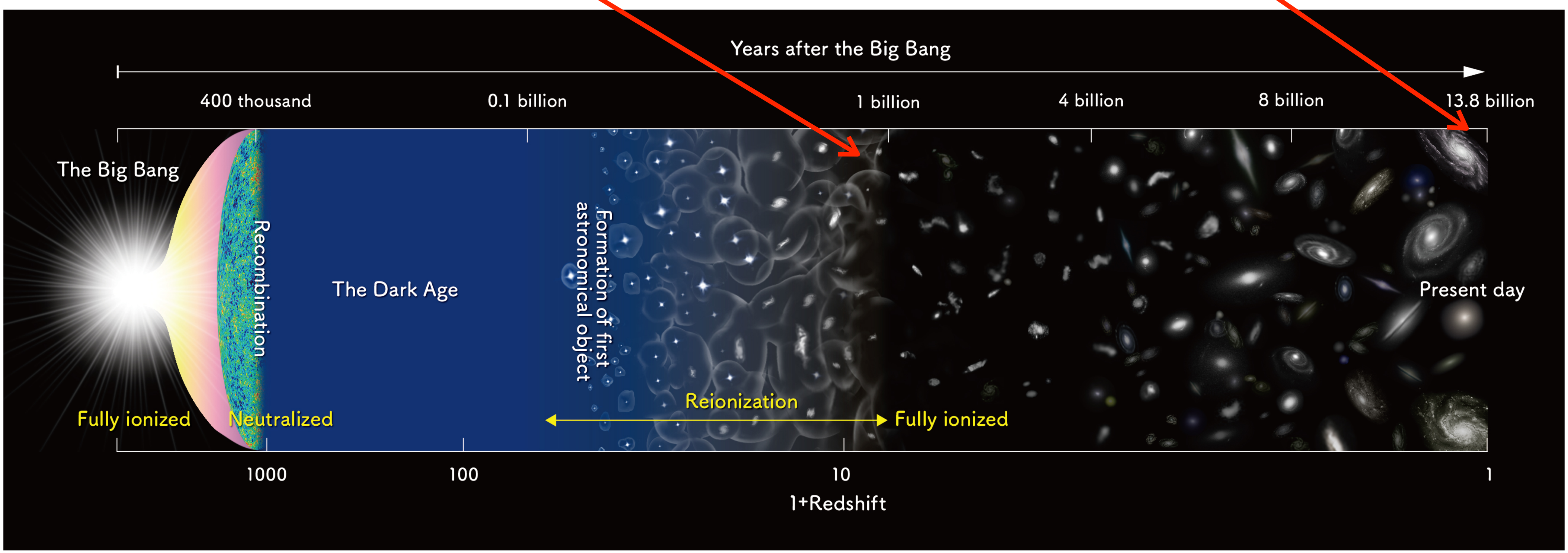


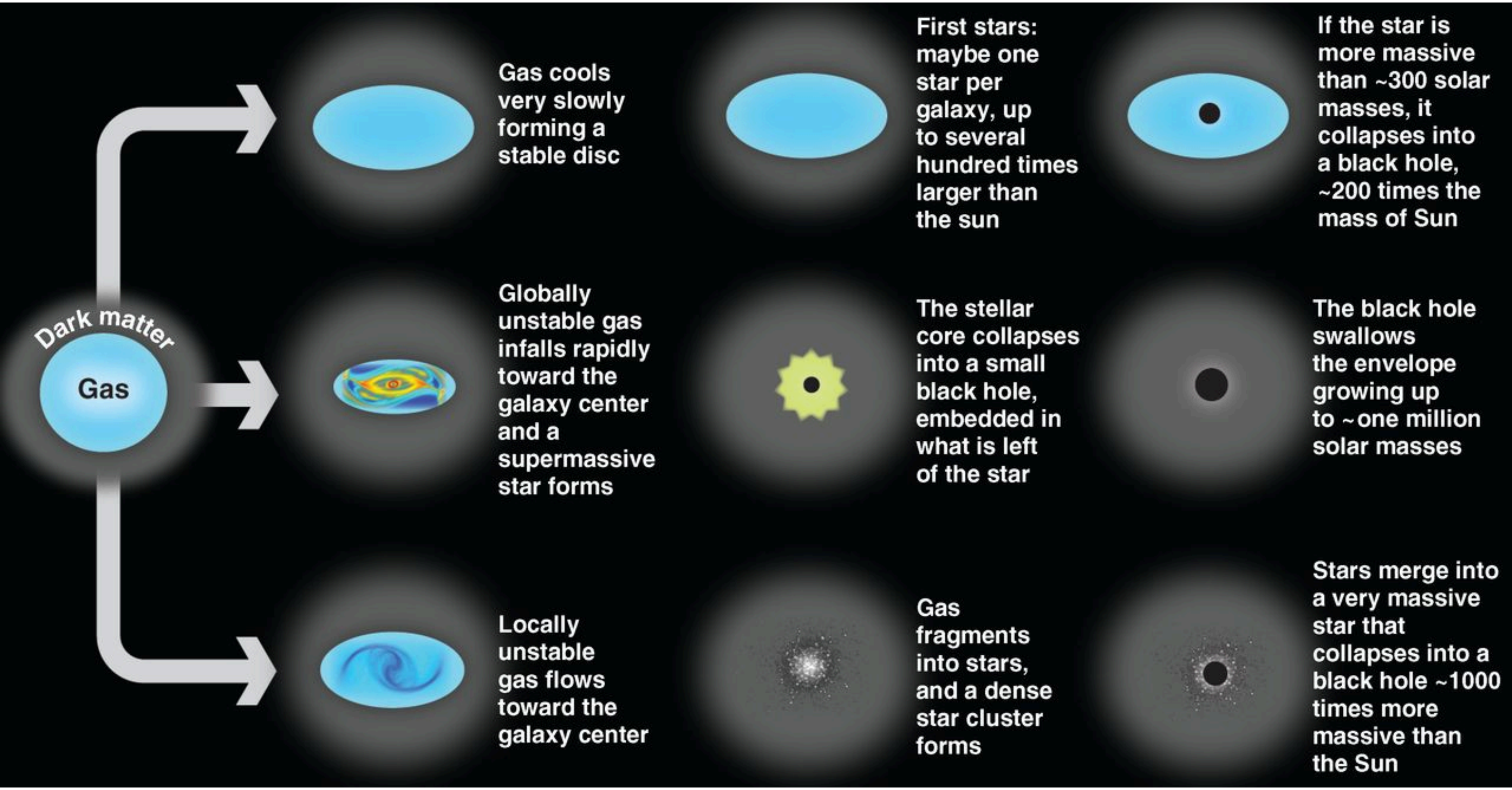
~10^6 — 10^9 $M_\odot$ Black Holes



8×10^{11} $M_\odot$ Black Hole!

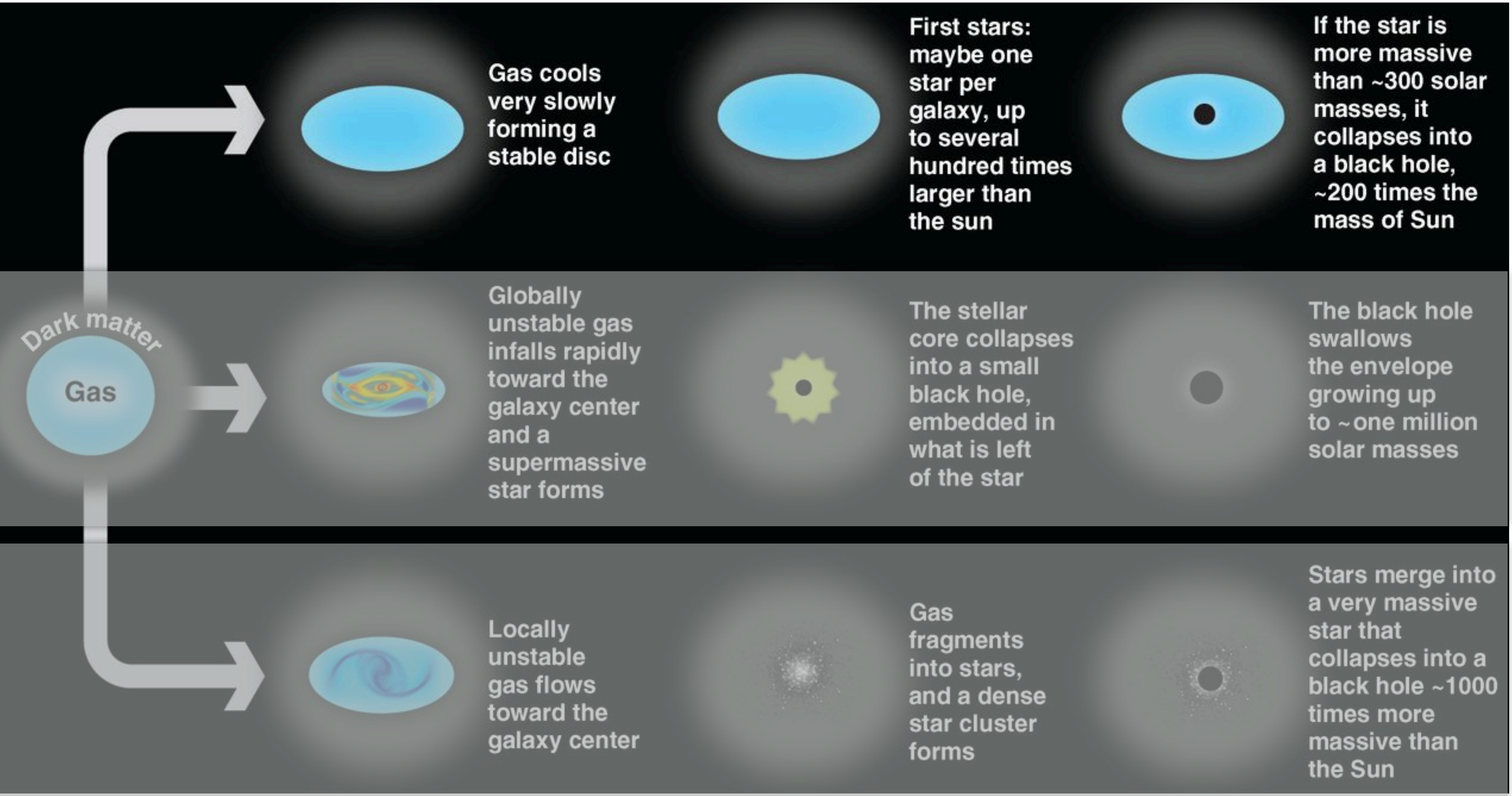


Forming a black hole: let me count (some of) the ways



From excellent Volonteri review

One channel: Light seeds from the first generation of stars

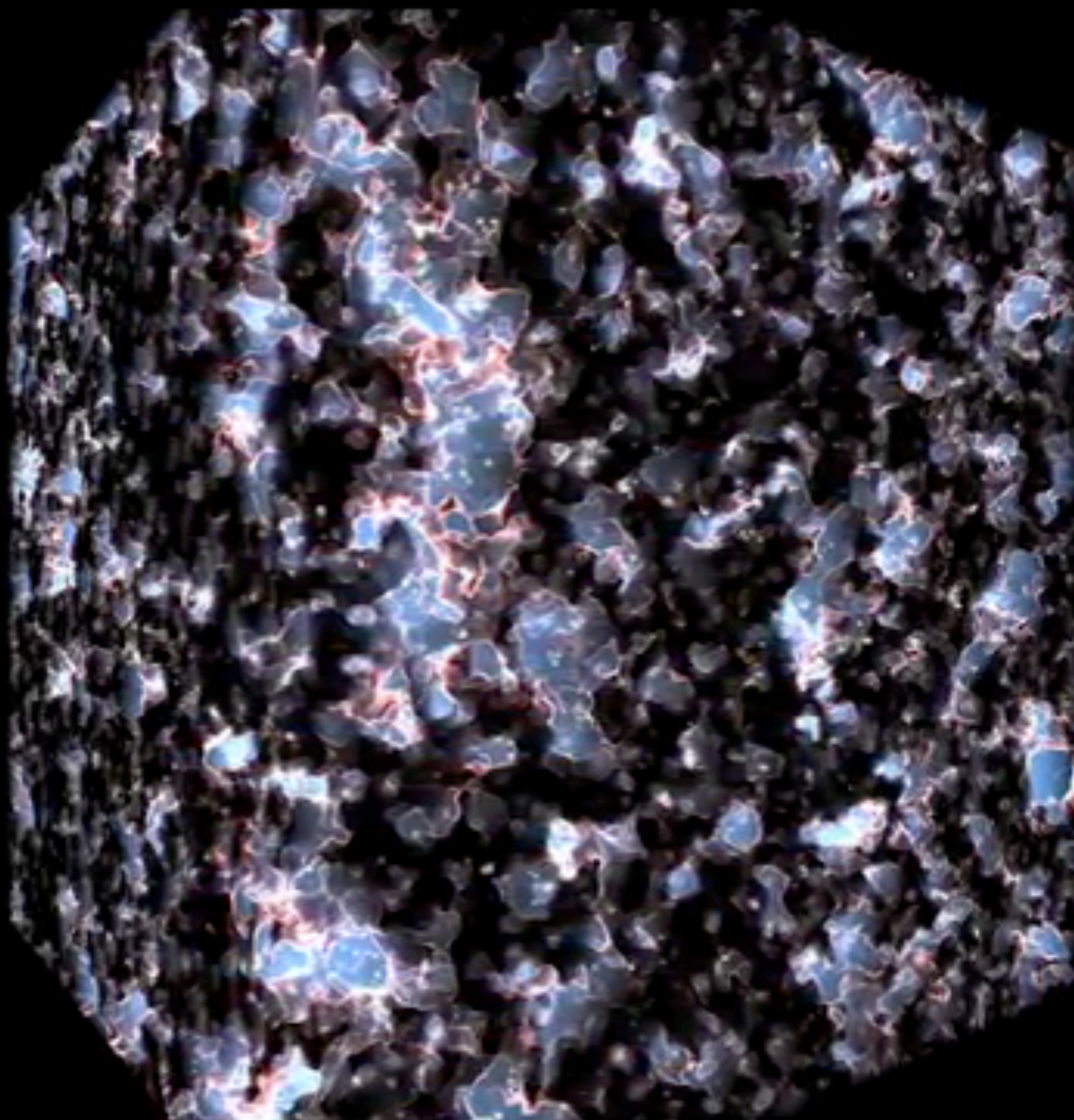


From excellent Volonteri review

The modern view of how the first stars are born…

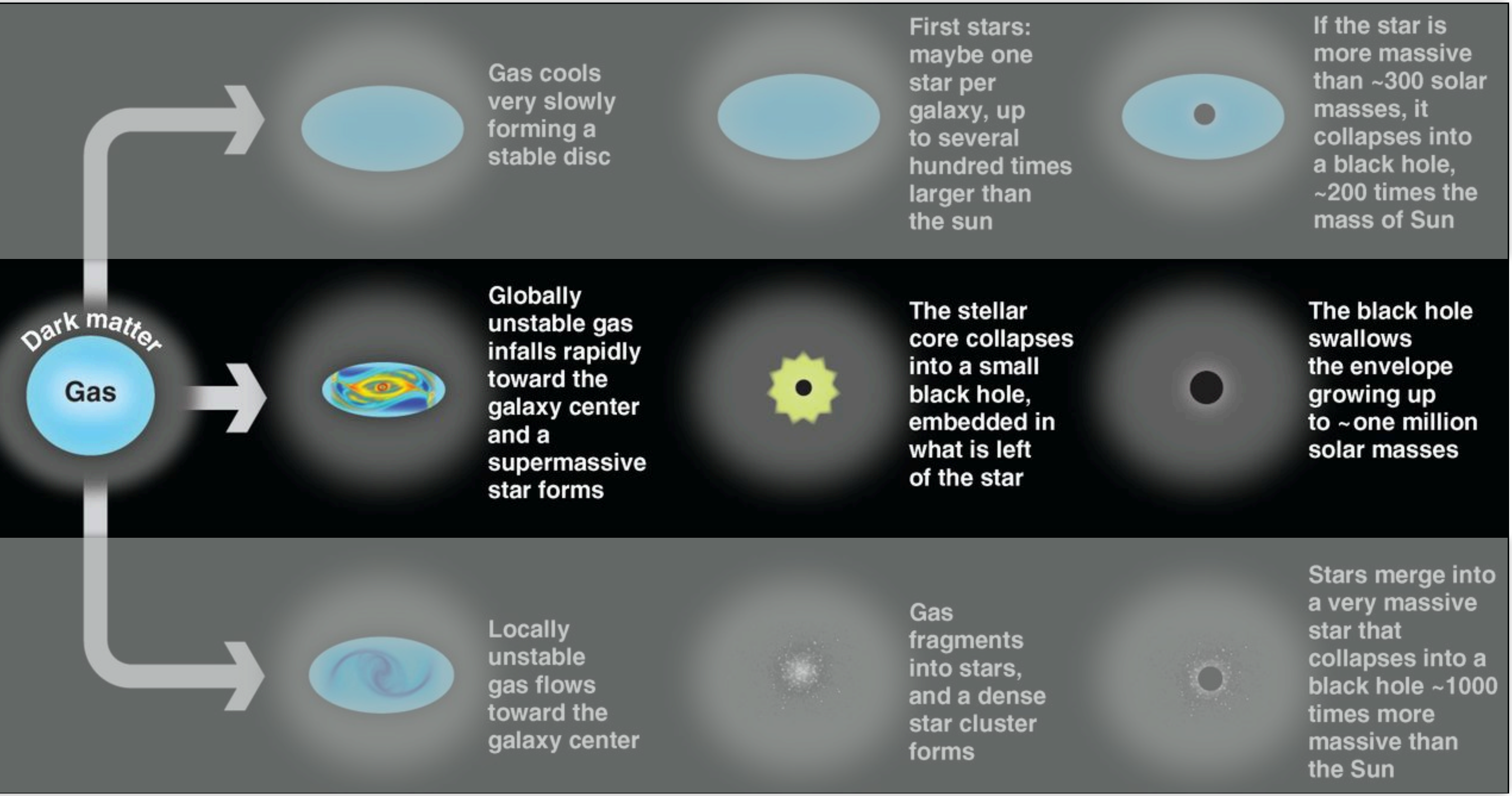
Smith et al. 2015

These first stars heat and reionize the universe!



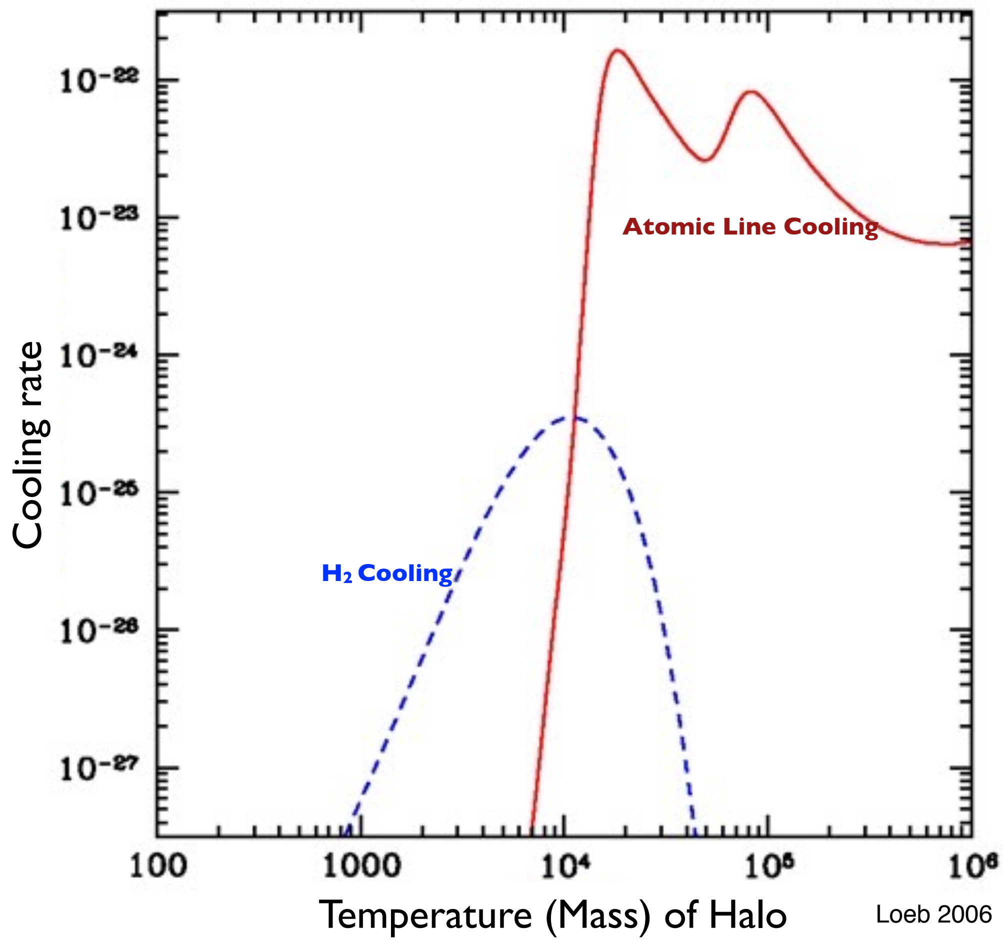
Credits: Simulation: Marcelo Alvarez, Tom Abel; Visualization: Ralf Kaehler

One channel: Heavy seeds from directly collapsing black holes

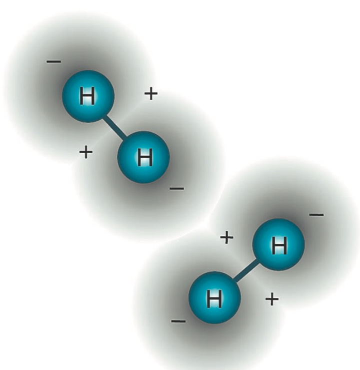


From excellent Volonteri review

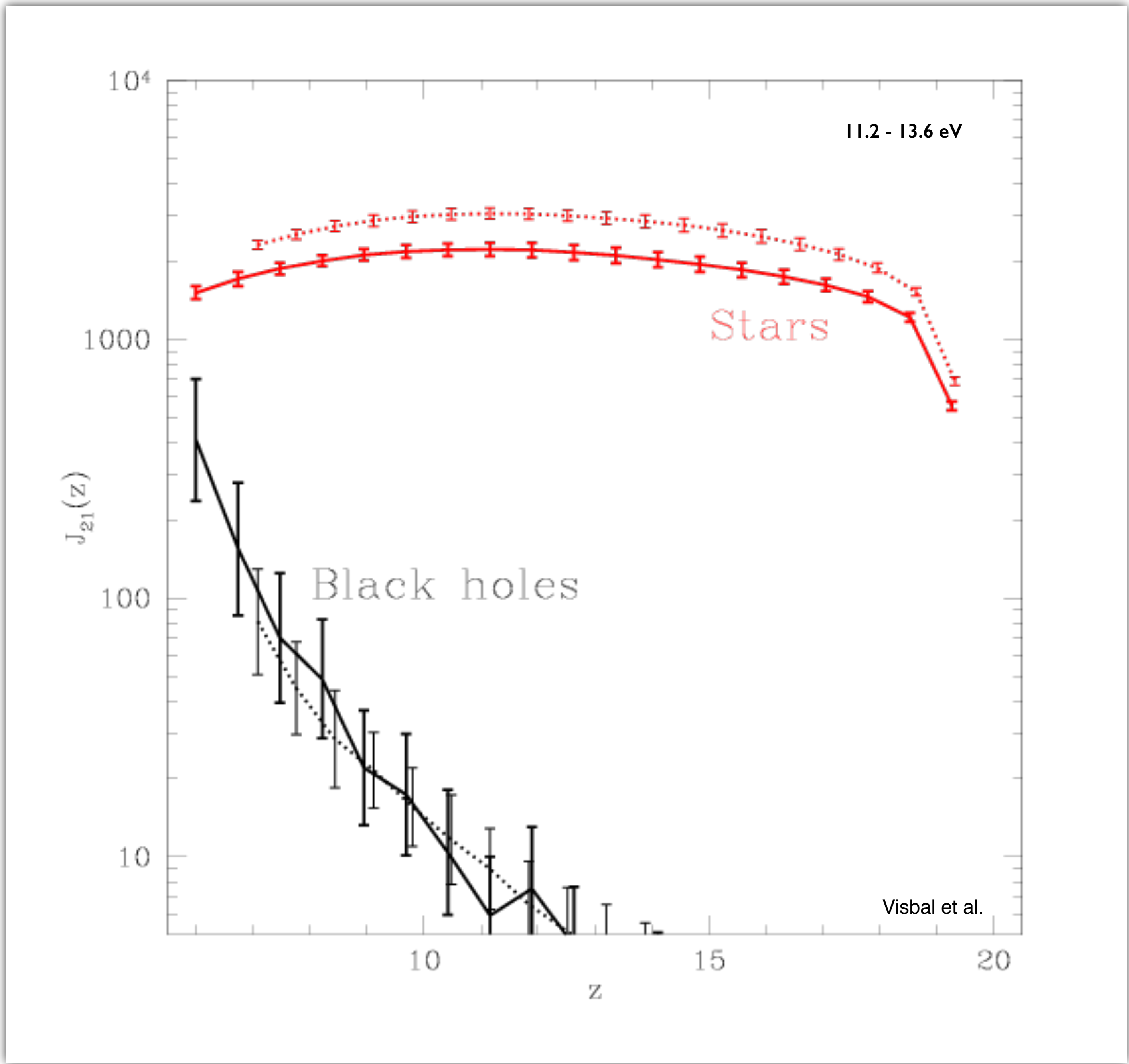
A problem: to build a heavy seed, gas must battle fragmentation!



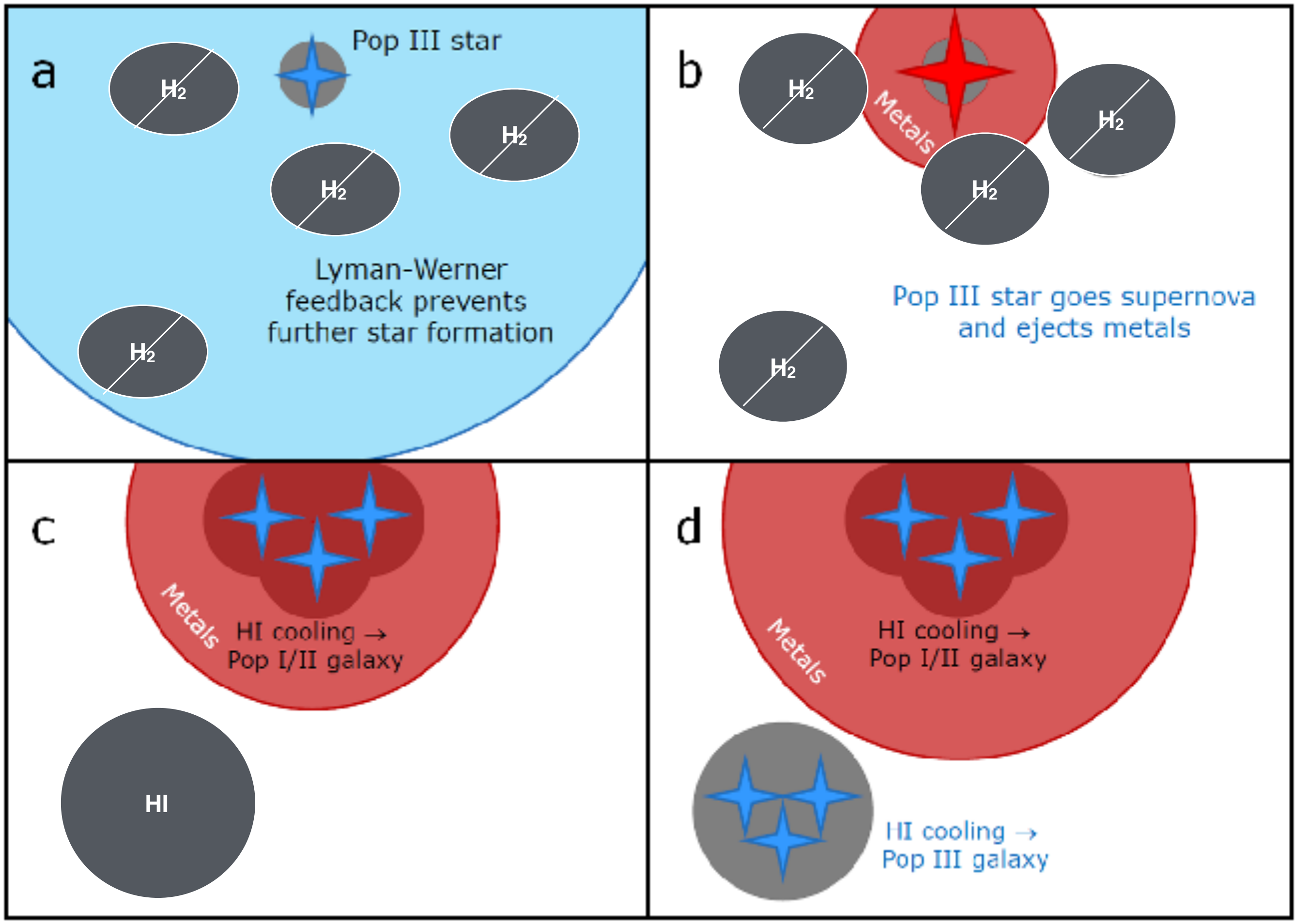
Once halo is polluted with metals, they really dominate cooling!



Lyman-Werner radiation from the first stars and black holes can dissociate H_2

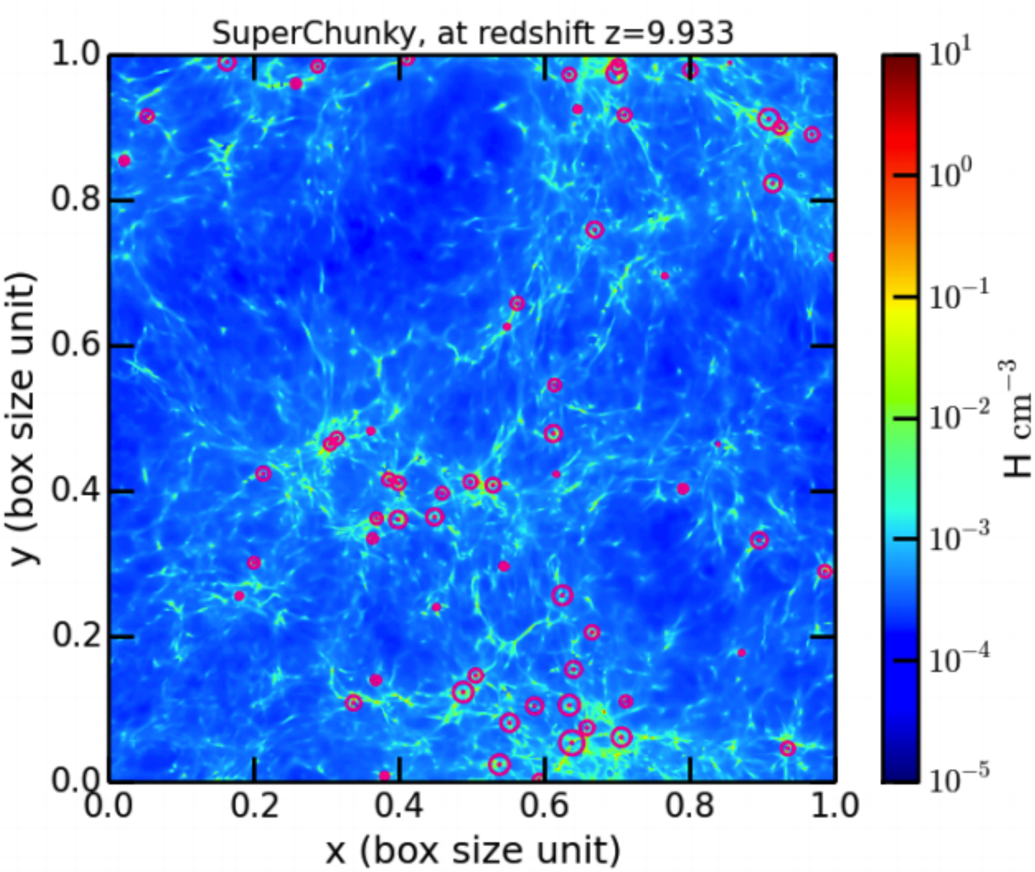


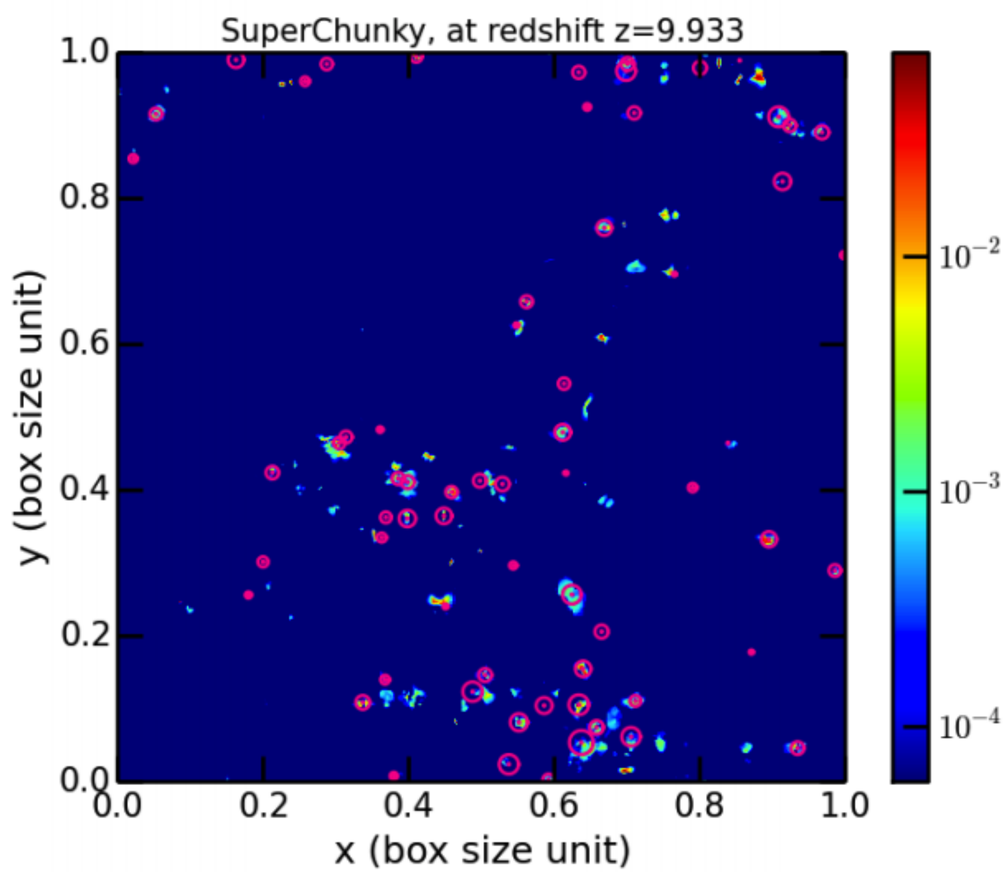
Low mass halos bathed in Lyman-Werner Flux can fo
Direct Collapse BHs



adapted from Zackrisson et al. 2012; see Visbal, Haiman, Bryan 2018

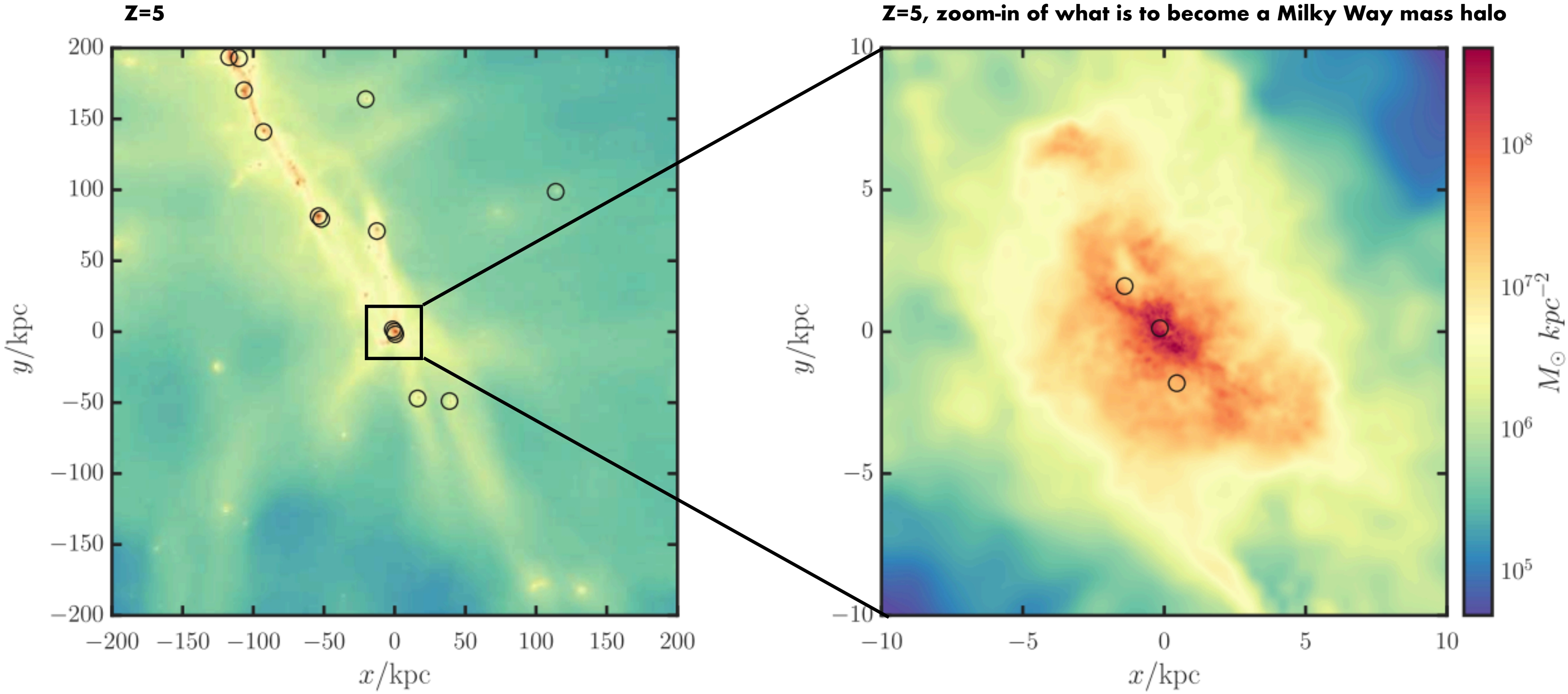
Early consensus: black hole birthplaces are rare with a uniform UV background





Habouzit et al 2016

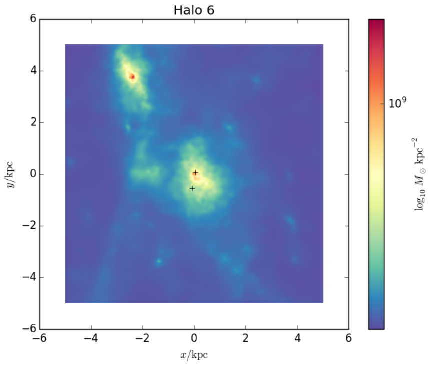
See also Agarwal et al. 2013; Akutalp et al. 2014; Khandai et al. 2014…

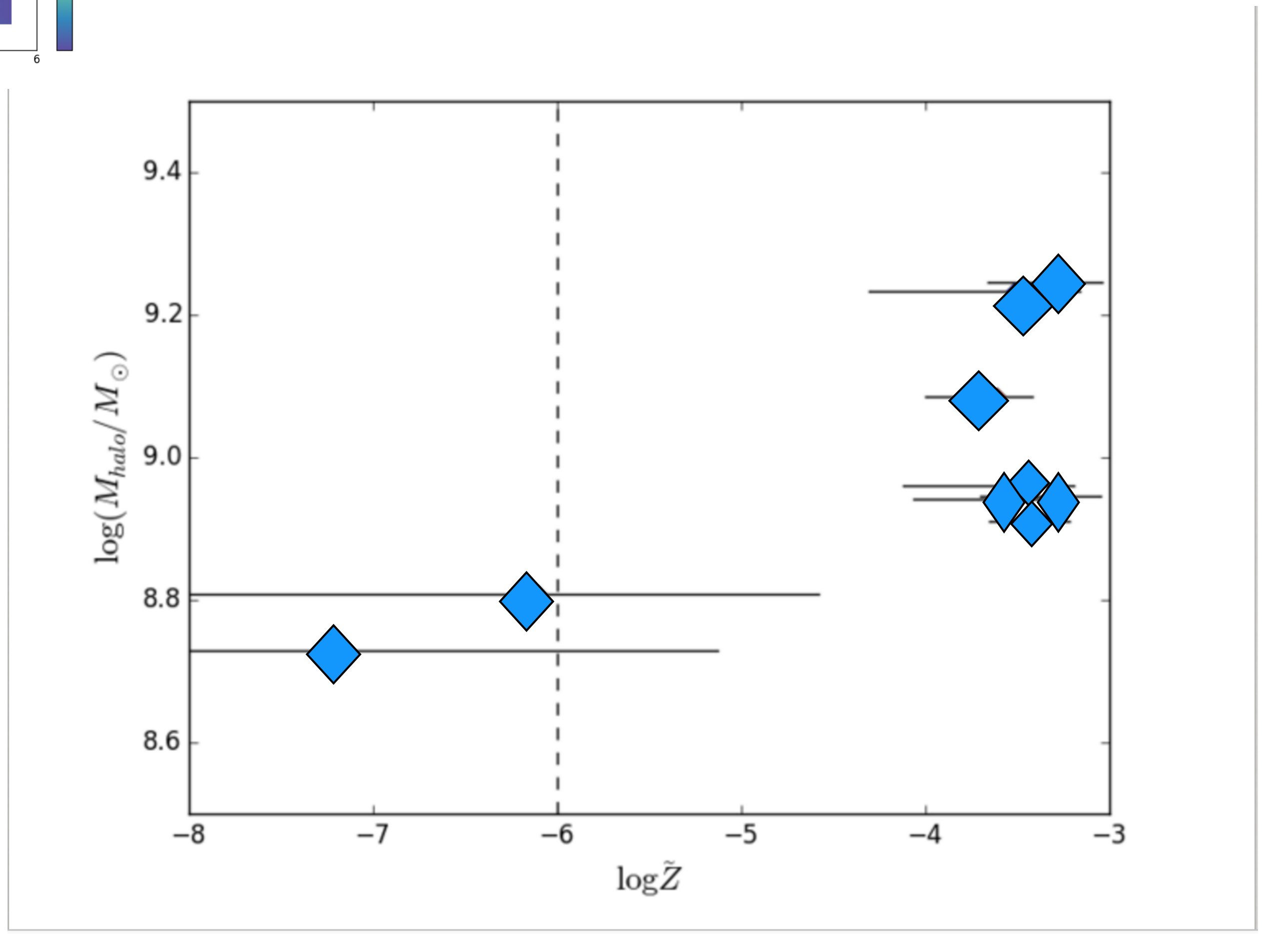


Cosmological Hydrodynamical Simulations of Direct Collapse Black Hole Formation

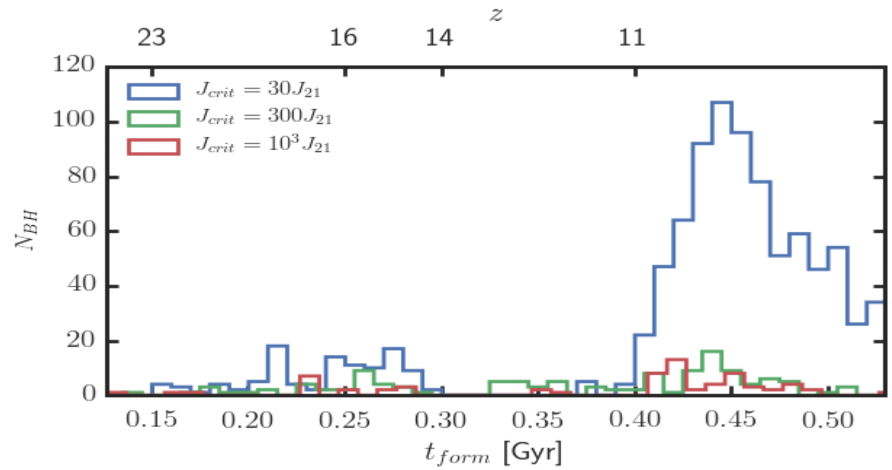
Dunn, Bellovary, KHB, Christensen, Quinn 2018

Surprises so far — several Direct Collapse Black Holes can form in a single halo

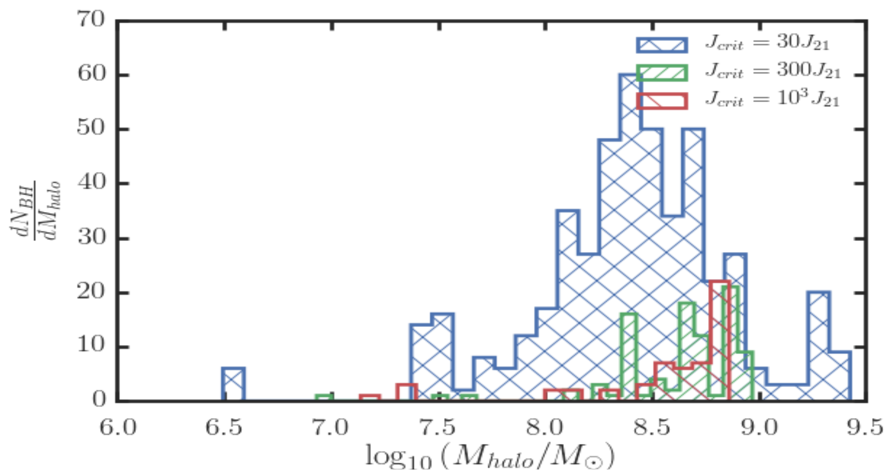




…and seeds can form in ‘high’ metallicity halos, too!

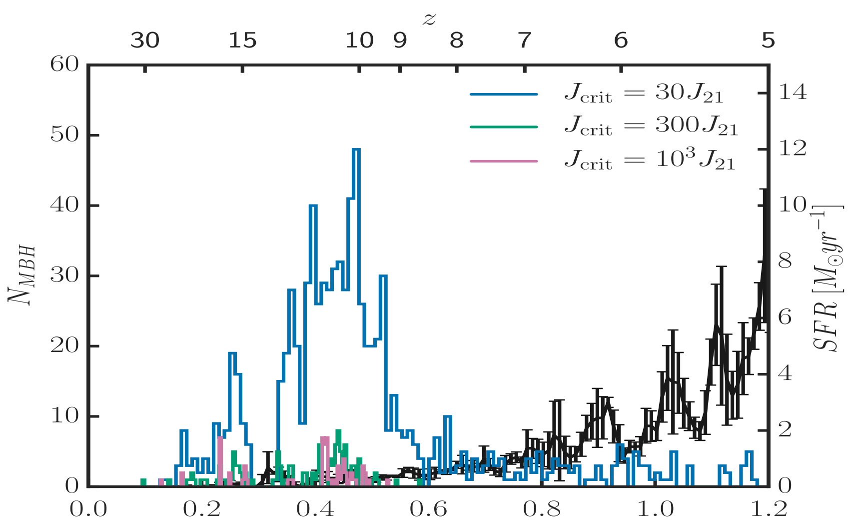


Seed black holes may form after reionization…



in a wider halo mass spectrum…

>50% of halos with masses ~10^8 $M_\odot$ host a seed BH by z~4



and may surpress early star formation…

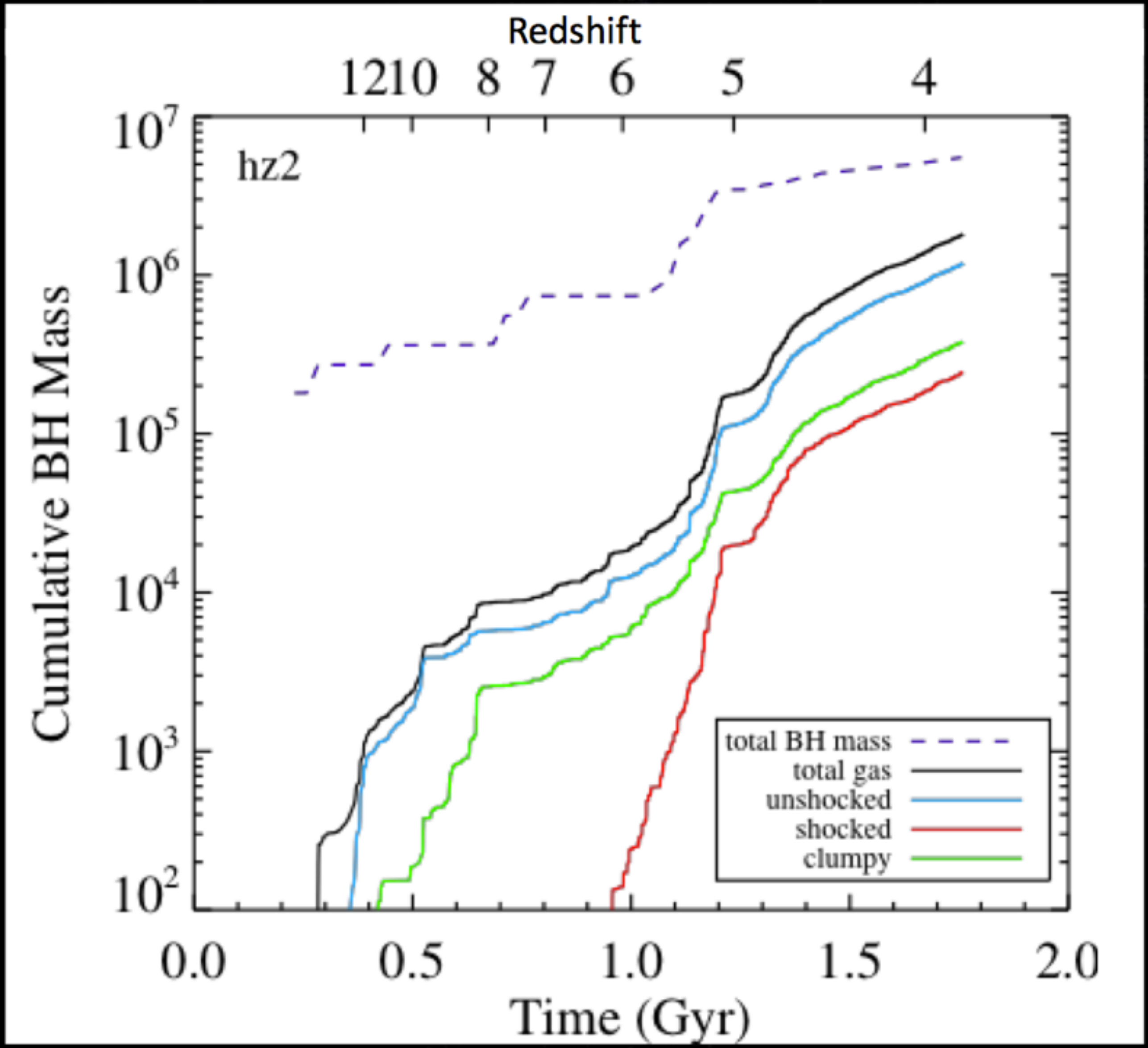
look for Dunn et al. 2018 on an arXiv near you.

How do these heavy seeds grow?

Bellovary et al. 2013

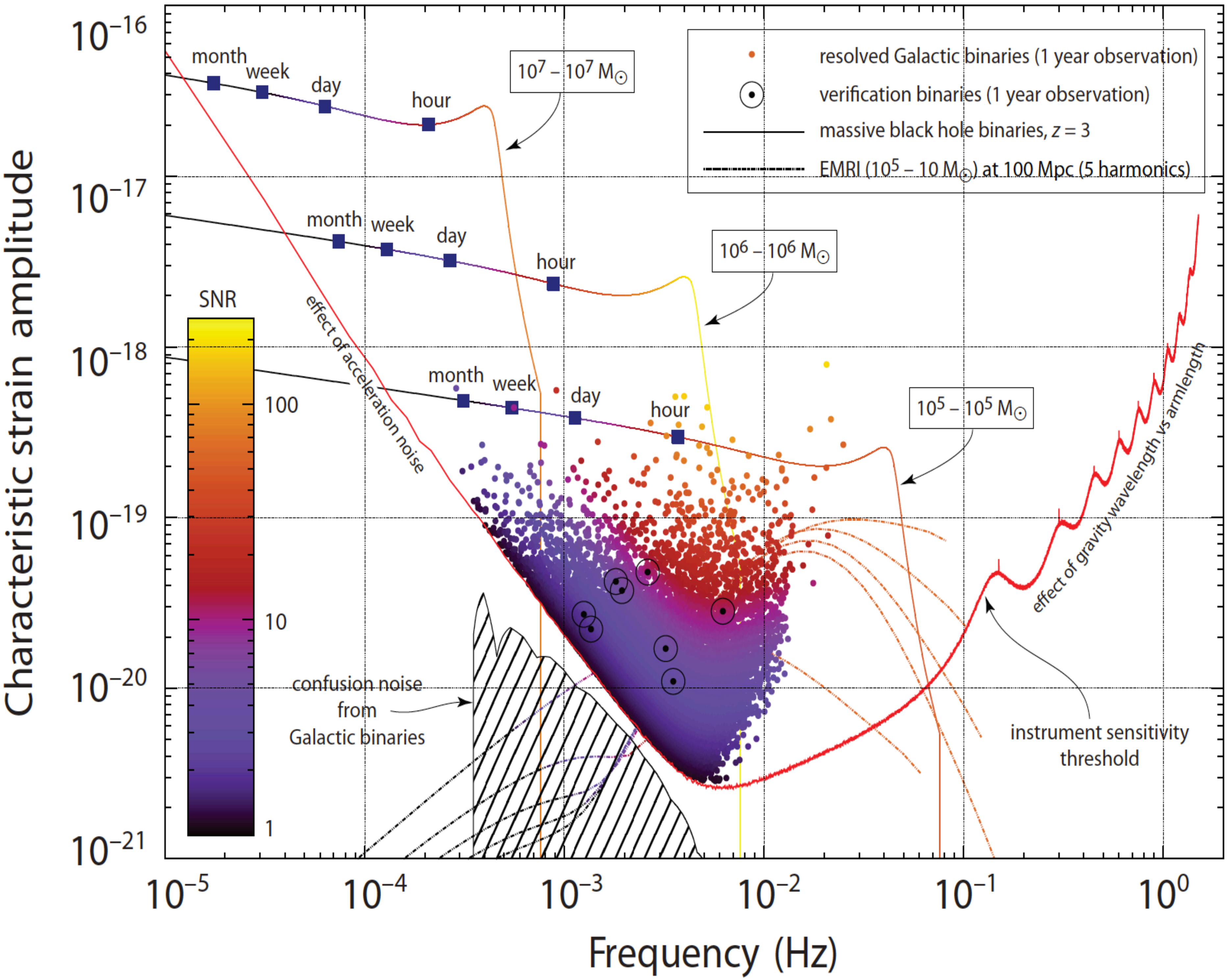
Most of the early SMBH growth is not from gas…

...and the gas that does fuel the SMBH is not from galaxy mergers



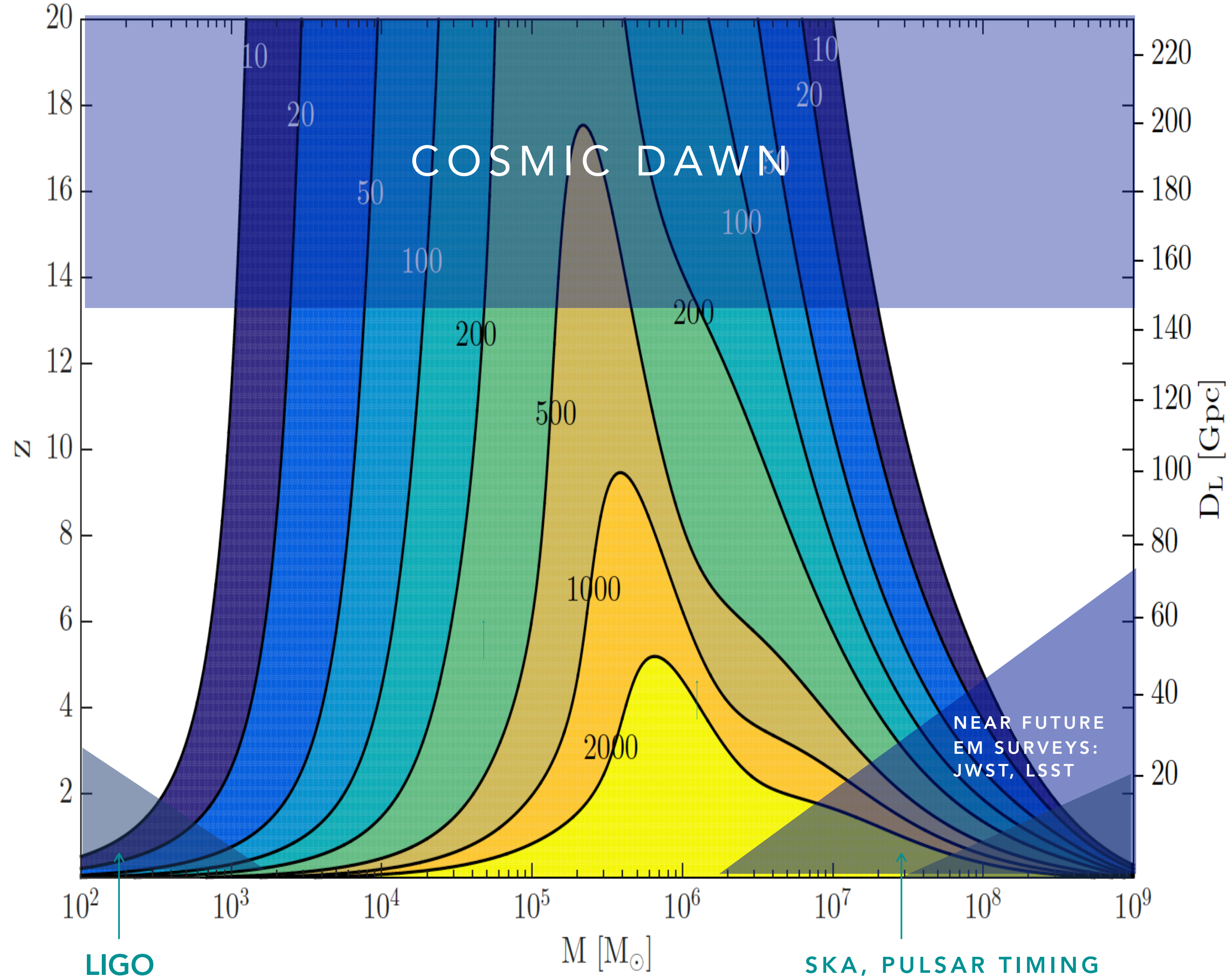
Sanchez, Bellovary and KHB, 2018

What does all this mean for gravitational wave astronomy?

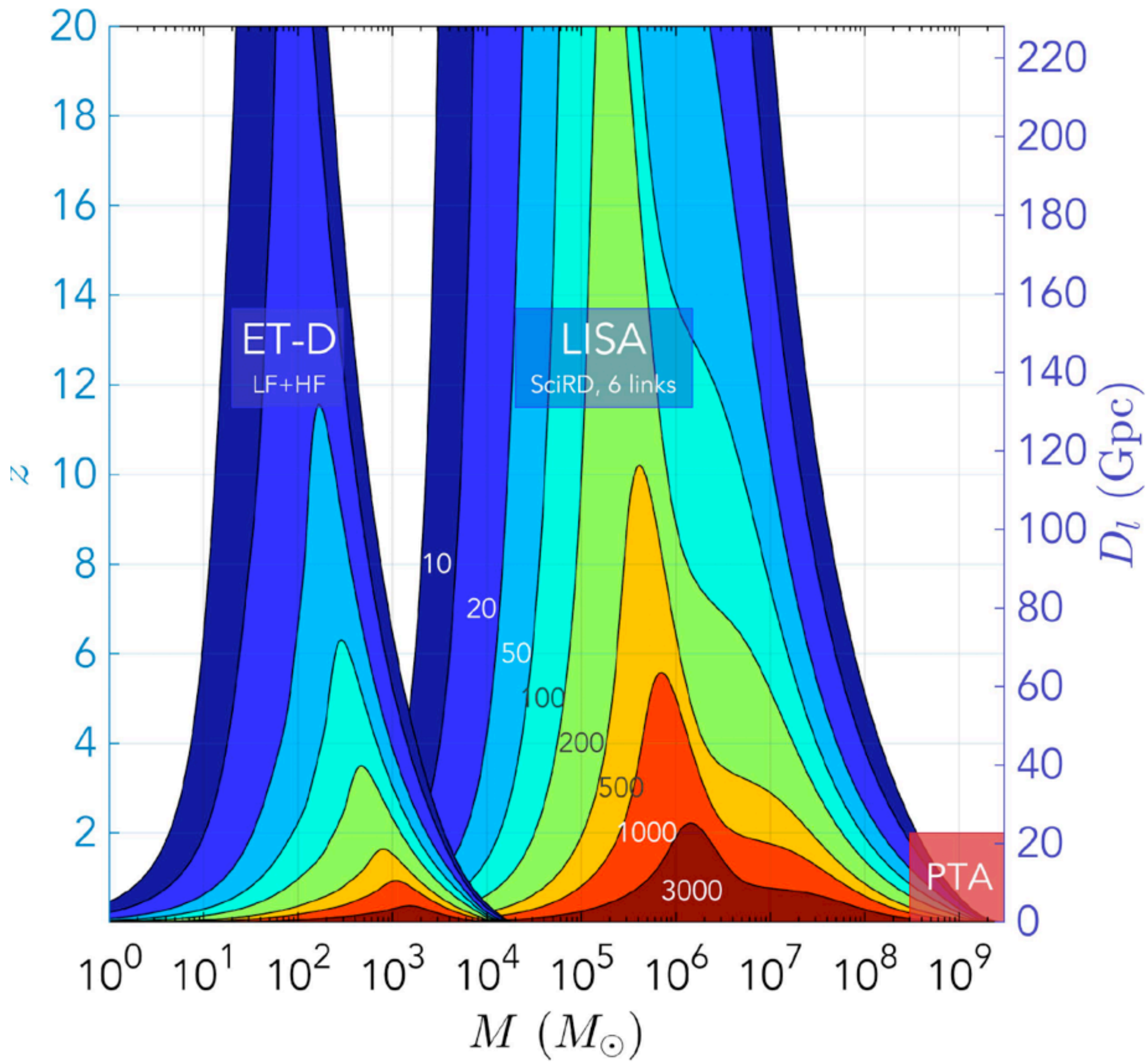


Characteristic strain amplitude
Frequency (Hz)
10^−16
10^−17
10^−18
10^−19
10^−20
10^−21
10^−5
10^−4
10^−3
10^−2
10^−1
10^0
month
week
day
hour
10^7 – 10^7 M⊙
10^6 – 10^6 M⊙
10^5 – 10^5 M⊙
resolved Galactic binaries (1 year observation)
verification binaries (1 year observation)
massive black hole binaries, z = 3
EMRI (10^5 – 10 M⊙) at 100 Mpc (5 harmonics)
SNR
100
10
1
effect of acceleration noise
confusion noise from Galactic binaries
effect of gravity wavelength vs armlength
instrument sensitivity threshold

Gravitational Waves will get the only* direct view of seed formation and black hole early growth!



LISA will have an exquisite view of seed BHs. Hopefully, 3G will too – could especially probe the lighter seed channel!



note: actual 3G configuration not selected yet

Glenna Dunn

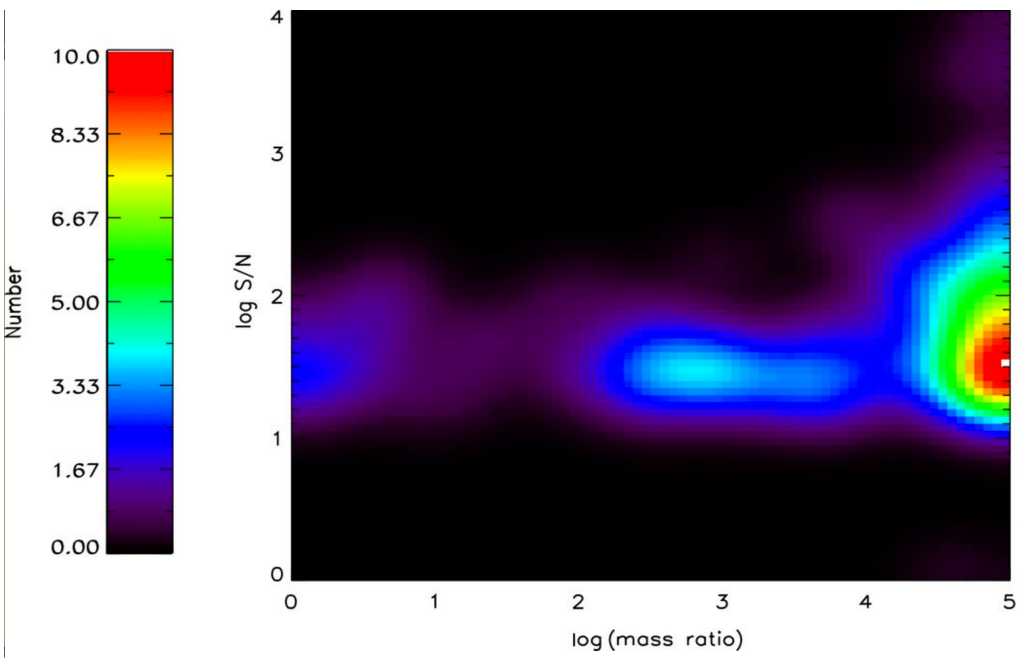
Than
ks!

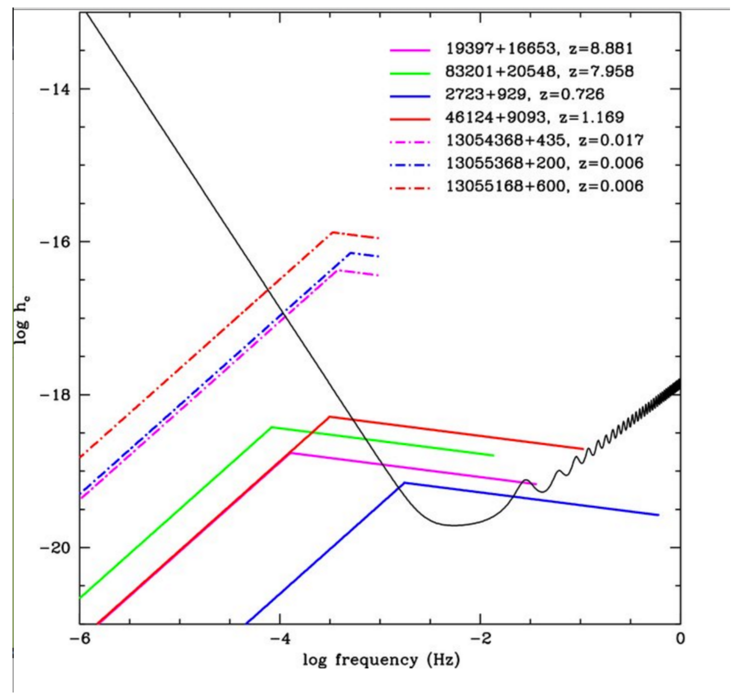
Jillian Bellovary

Nicole Sanchez

Assembling a MW SMBH results in dozens of loud signals, mostly with really unequal masses

scaling to the universe, ~ 500 sources with SNR>30 fo

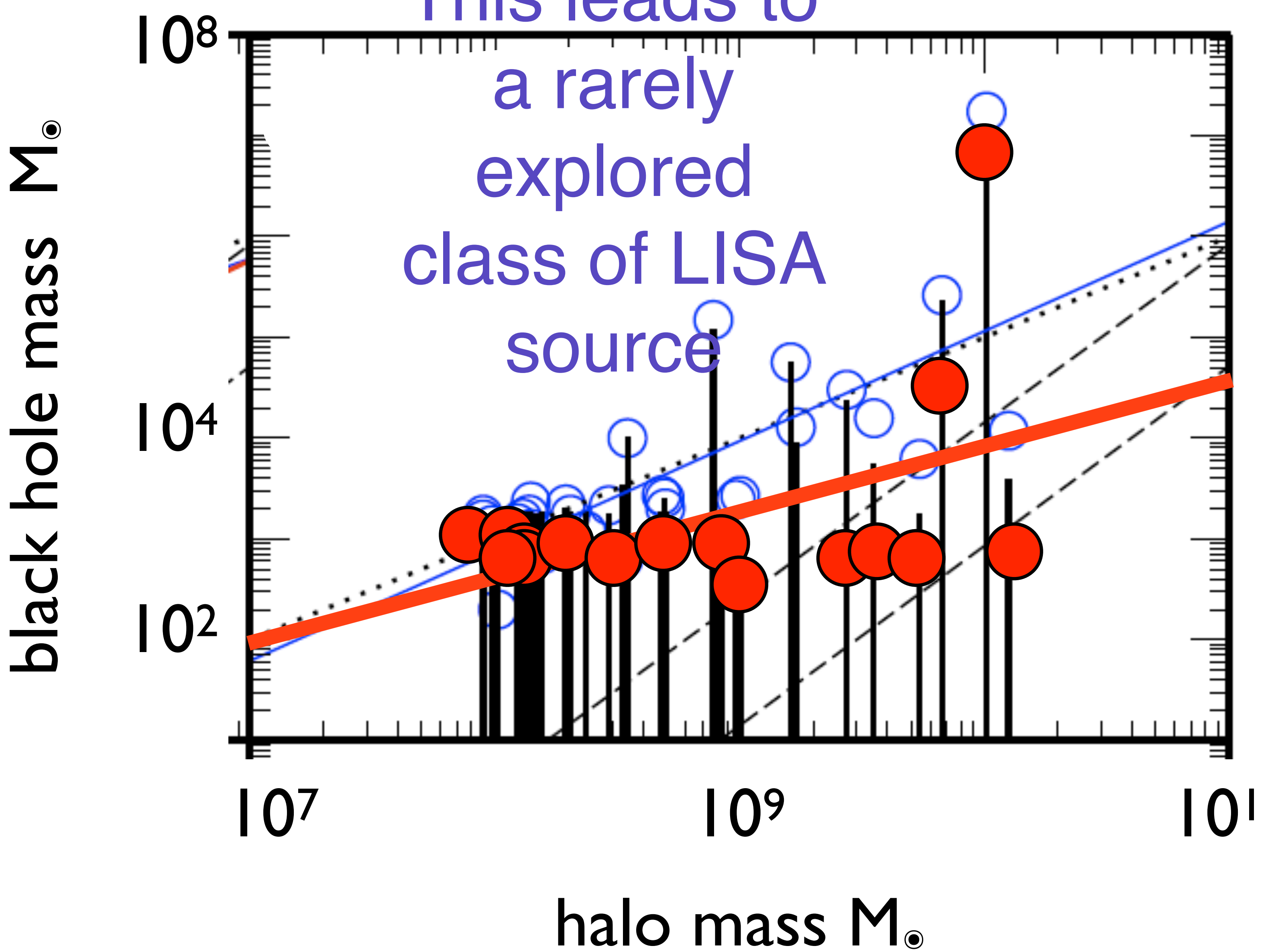




Dwarf galaxies may also have central black holes

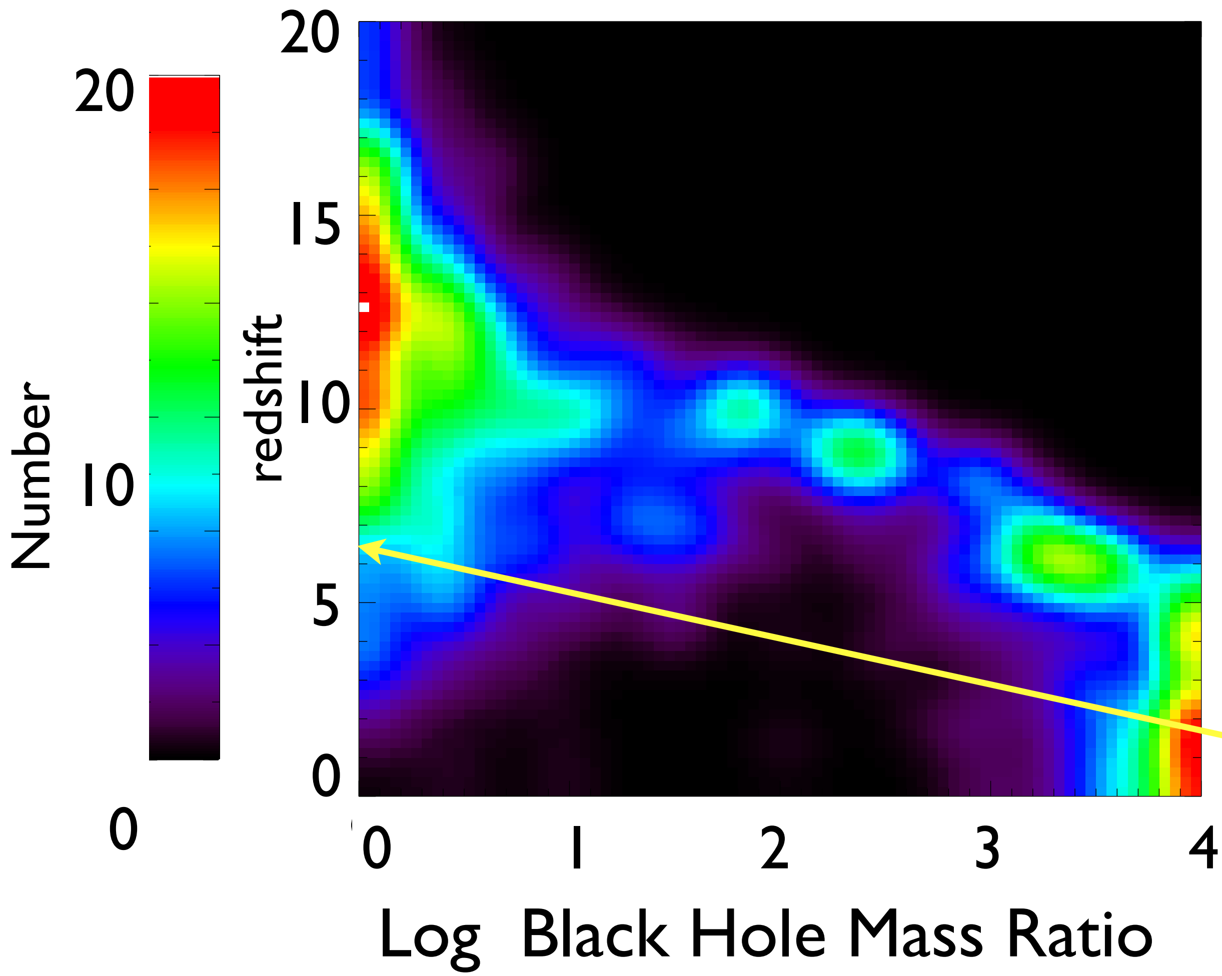
see also Micic, KHB 2007, Volonteri + Priya 2009, Per
2010

This leads to a rarely explored class of LISA source



Light SMBHs (like our own) don't assemble from equal mass (or even nearly equal mass) mergers

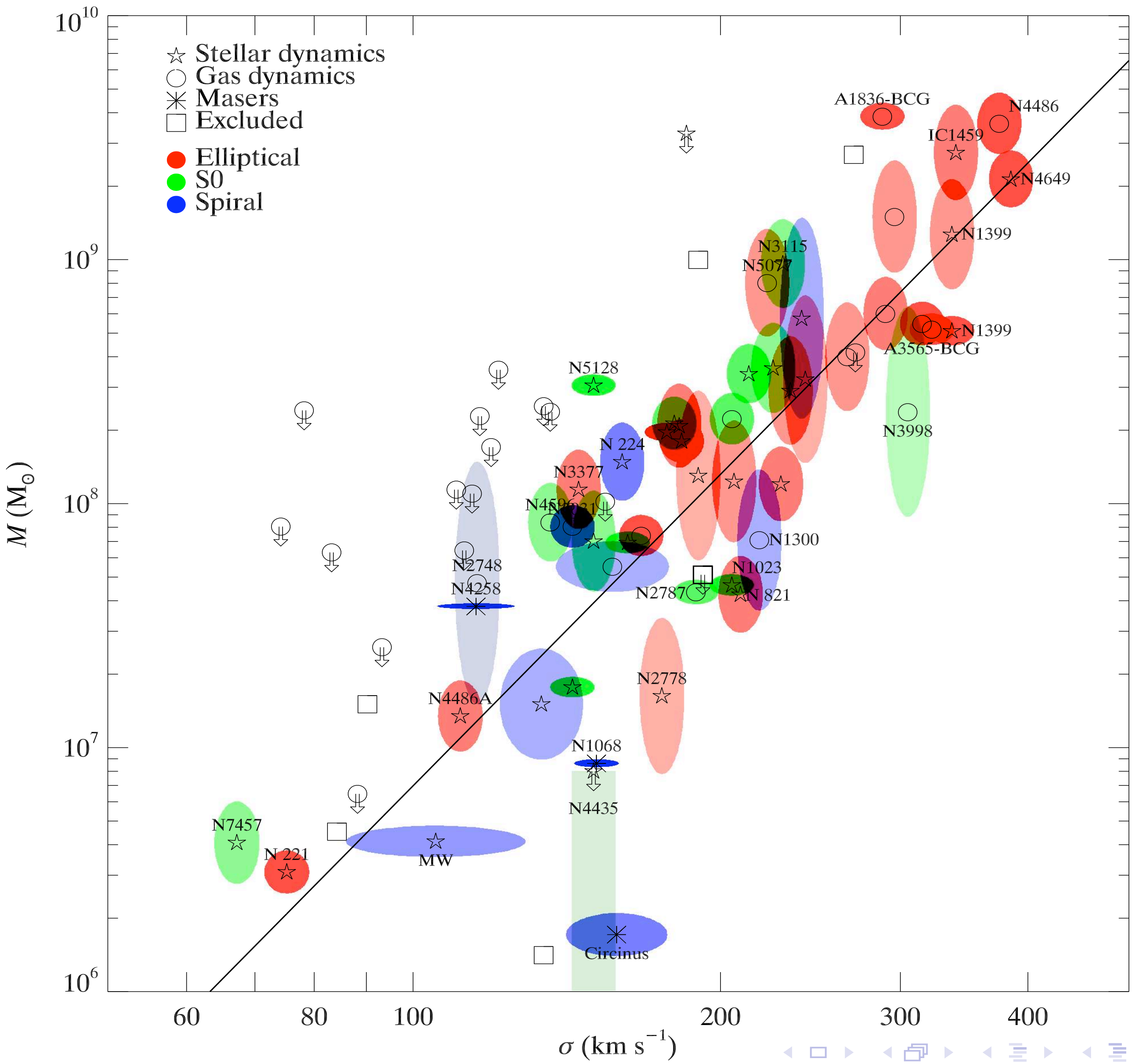
KHB et al. 2010

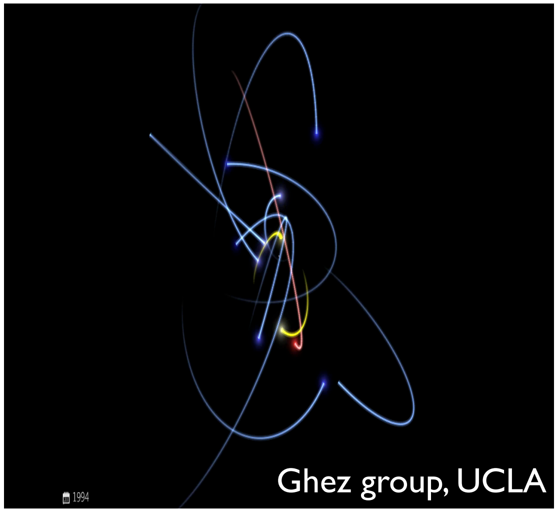


after the dark ages, there are few major mergers

Massive central

A Supermassive Black Hole for 'Every' Galaxy





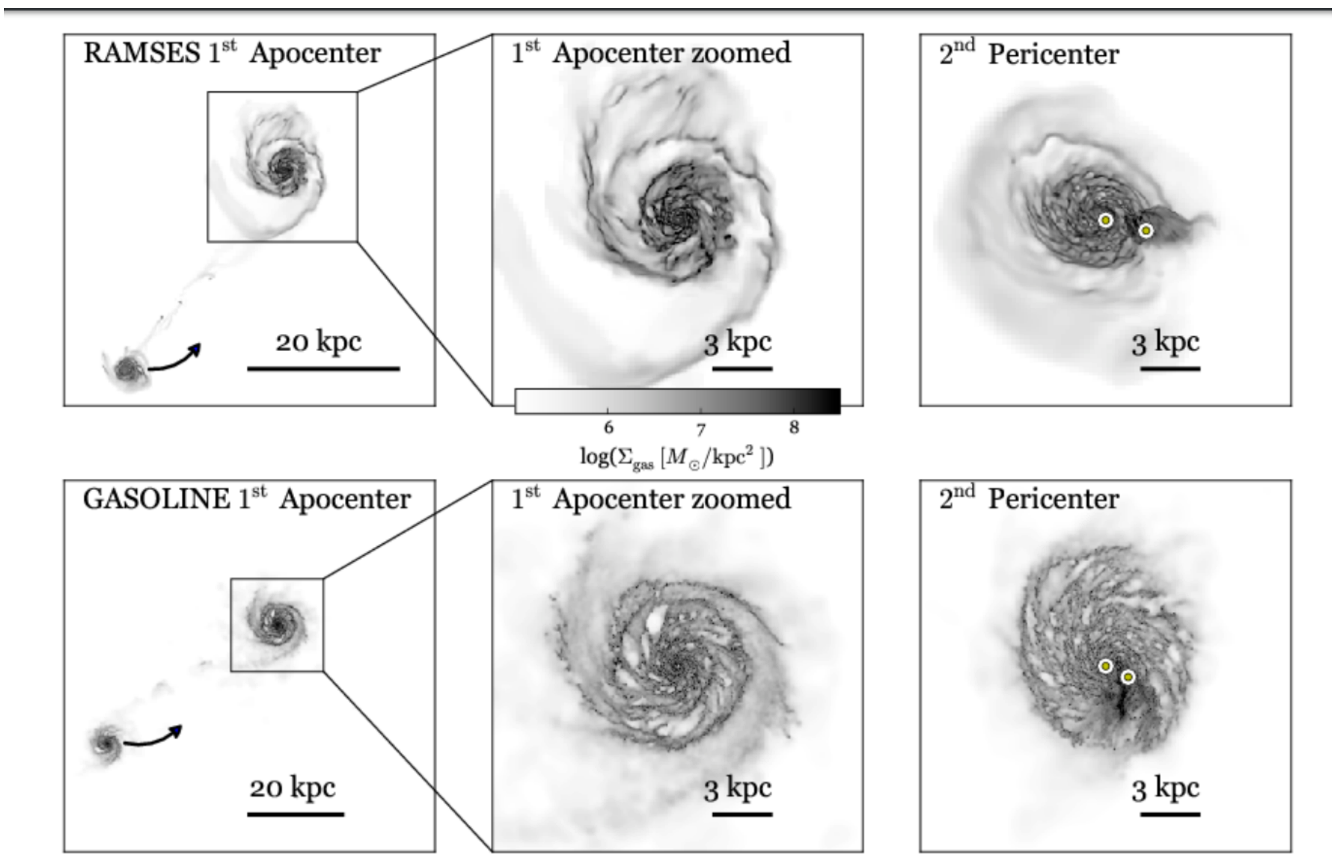
$R_{sch}=2\ G\ M/c^2=O(10^{-6})$

$R_{infl}=G\ M/\sigma_0^2=O(10^0)$ p

$R_e=O(10^3)$ pc

Gultekin et al 2009 -- see also Gebhardt et al 2000; Ferrarese & Merritt 2000: McConnell+Ma 2013, and work is on-going…

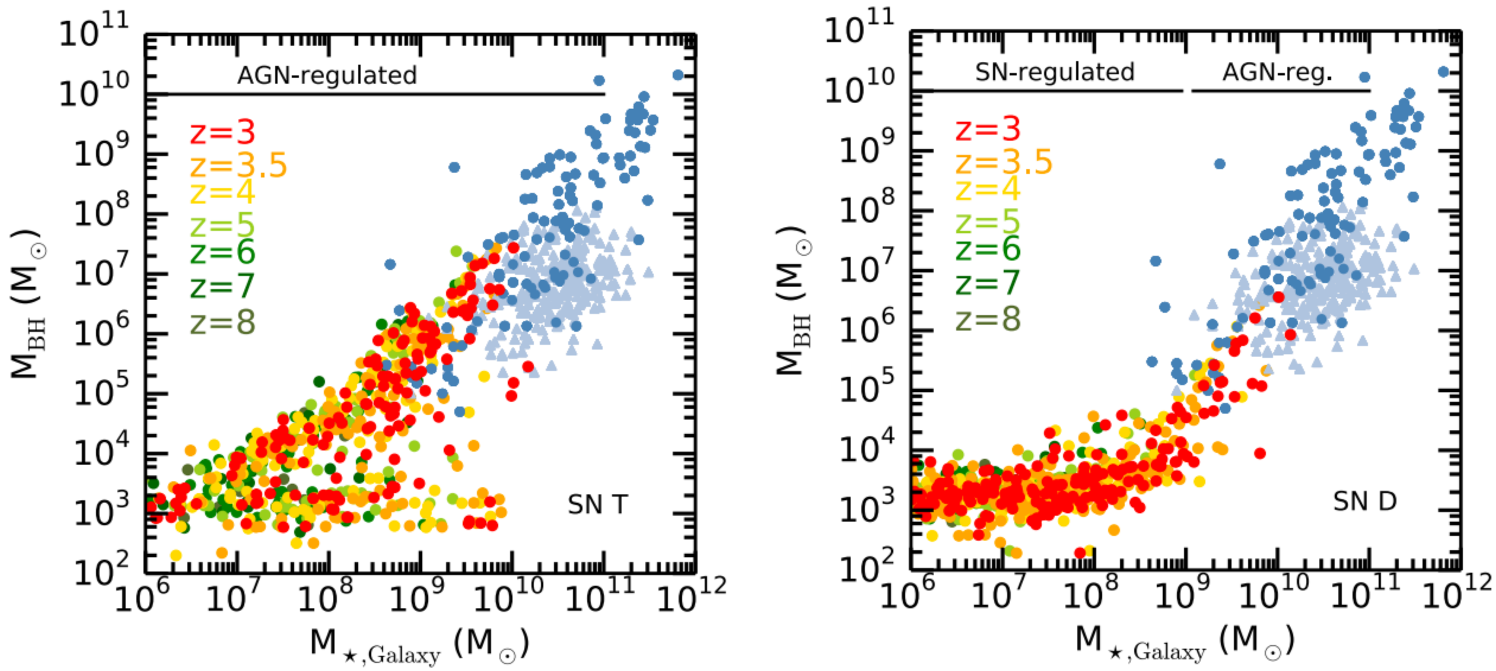
Warning: BH growth depends on the hydrodynamic code



BHs grow less, take longer to merge

Gabor et al. 2015

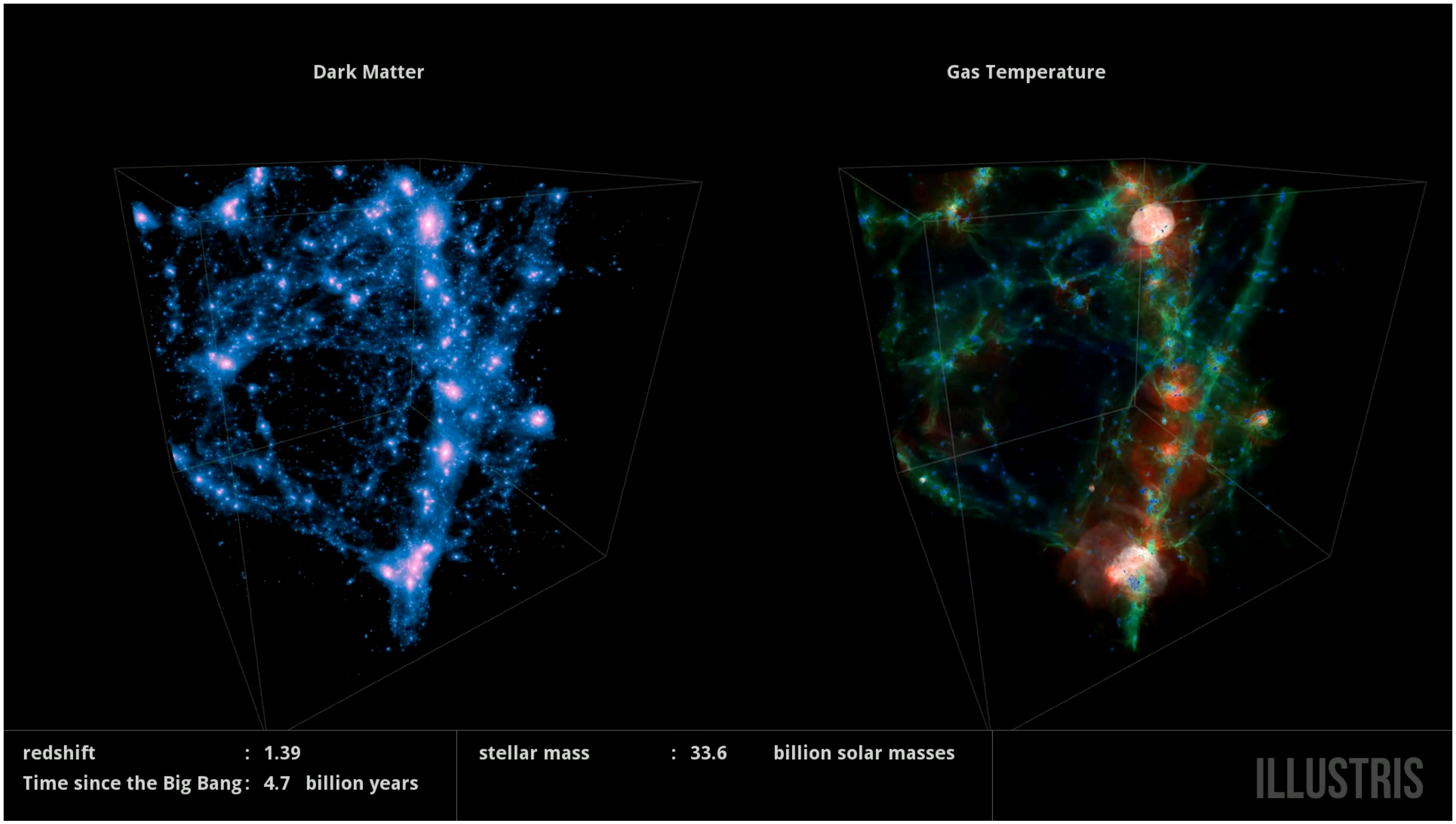
Warning: BH growth depends on a feedback recipe



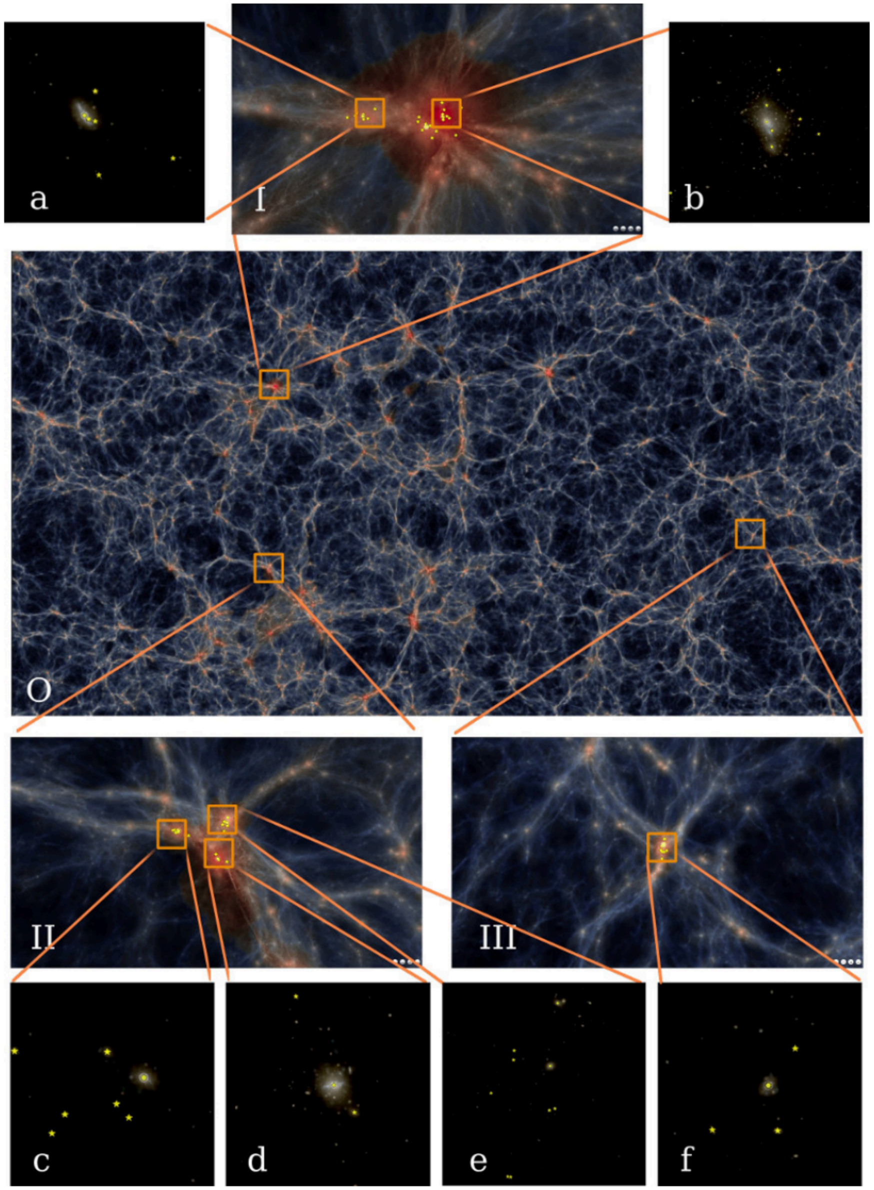
(!) box
Habouzit et al 2016
see also Dubois 2015

Warning: Over-zealous AGN feedback stifles BH growth (and star formation, too)

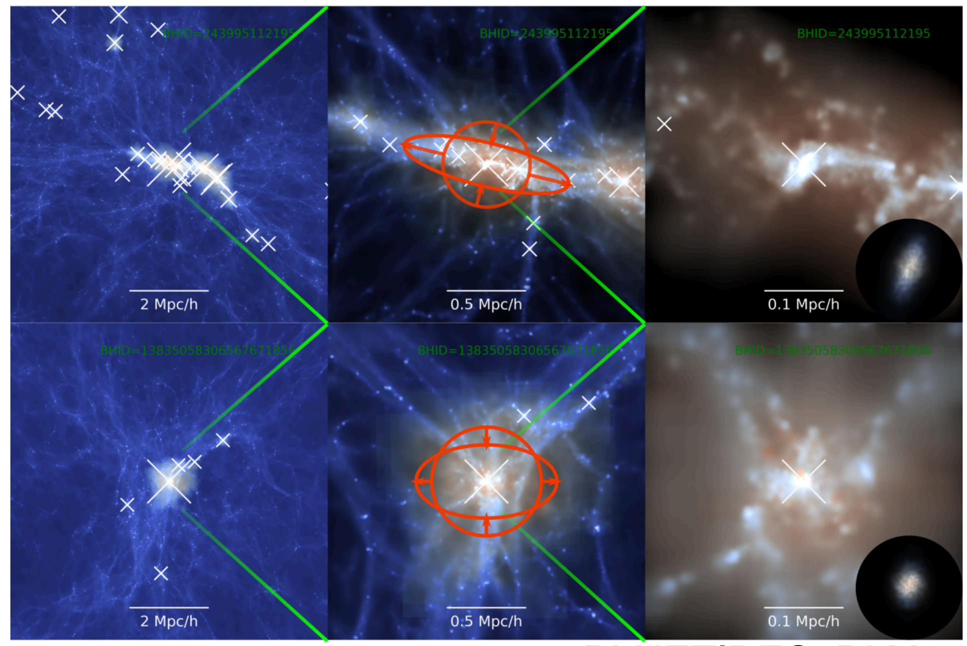
Volgelsburger et al. 2014



Stay Tuned: Large volumes with high resolution may help constrain black hole evolution



MassiveDark II, Khandai et al. 2014



BLUETIDES, Di Matteo et al. 2016

Step 0: measure a black hole mass

Step 1: relate BH mass to host galaxy

Step 2: find evidence of binary black holes

Step 3: measure galaxy merger rate to constrain SMBH merger ra

Step 4: Sow SMBH seeds

Step 5: Model SMBH growth

Step 6: Model SMBH merger dynamics to get merger timesca

Step 7: Find the strain, SNR for each merger

t’s a wonderful era to be an astronomer!

We need to get robust SMBH masses and pin down SMBH binaries

We need to know the real SMBH-galaxy correlation

We don’t know how black holes are born

We don’t understand SMBH accretion and feedback (including secular mass growth from, e.g., stellar plunges)

We need to include accurate SMBH dynamics in predictive models

Heinze 2-10 is dwarf with a million solar mass black hole

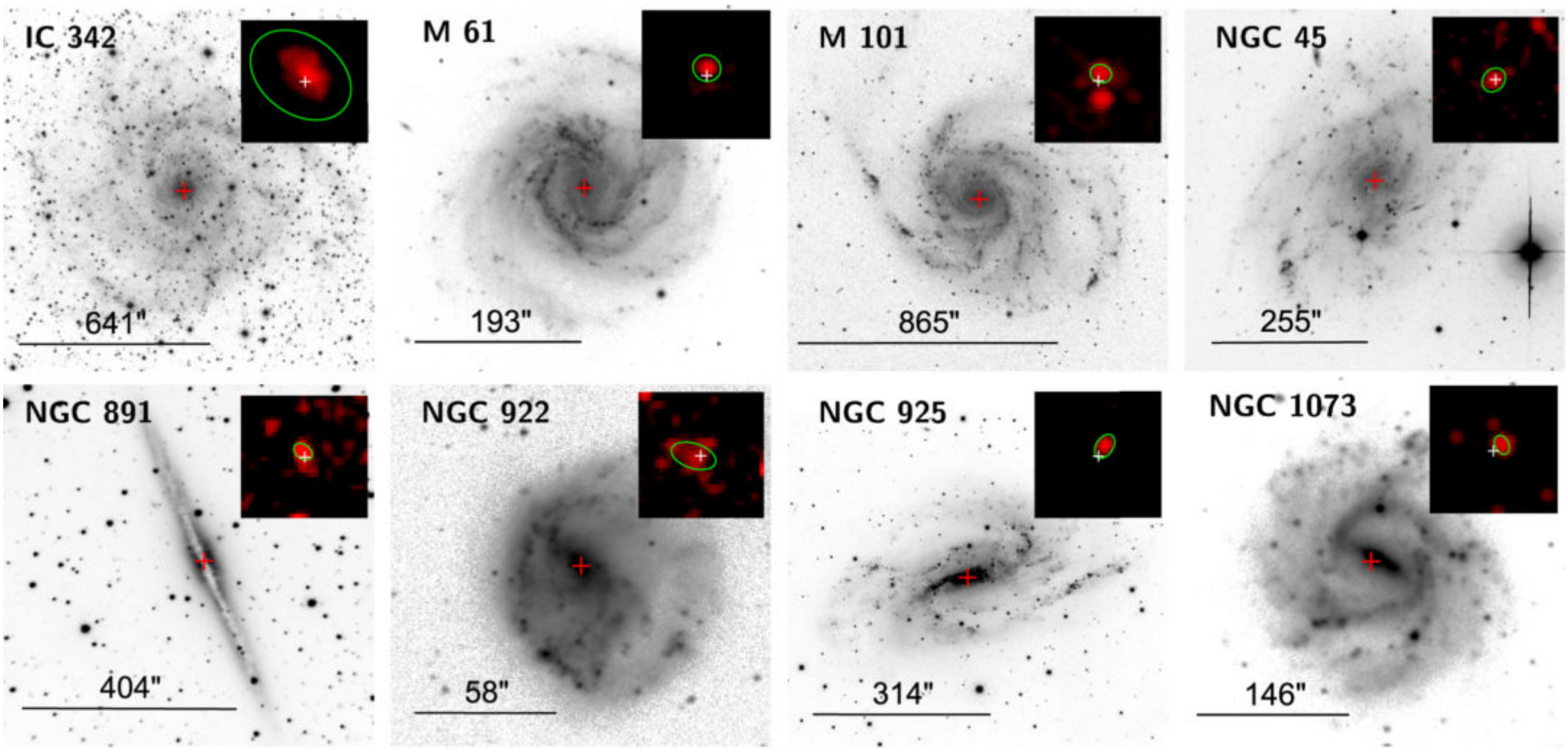
and there are SMBHs in bulgeless galaxies,

…and in low surface brightness galaxies, like Malin 1

Subramanian et al. 2015

Warning: viral masses — assume line width maps to velocity for Keplerian motion

Chandra reveals new SMBHs with $<10^6$ solar masses in galaxies



She et al 2017 — 21% of disky galaxies host SMBHs like these.

Evidence of an intermediate mass black hole --- in the outskirts of a galaxy