The formation of the first massive black holes via direct collapse of gas

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with
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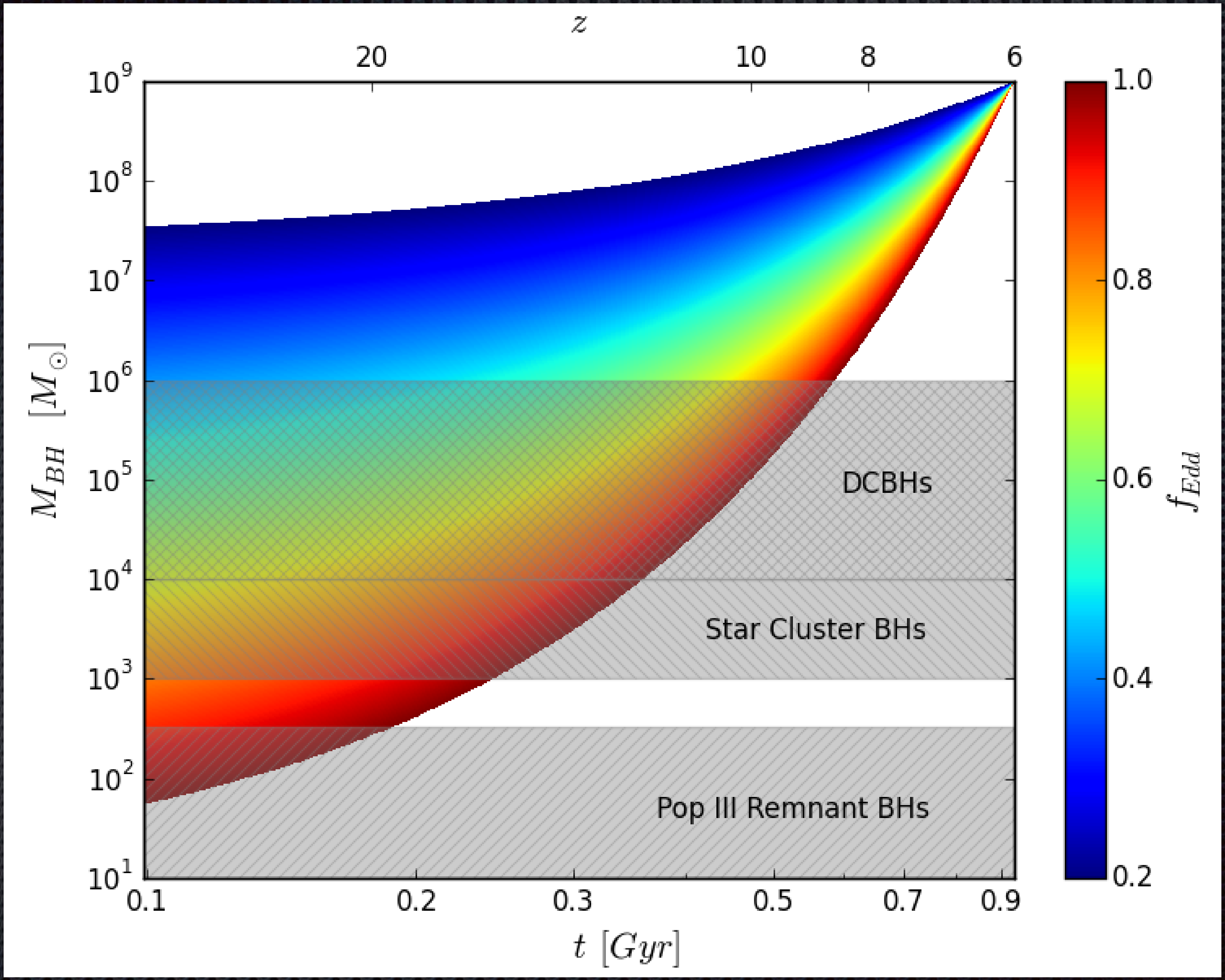
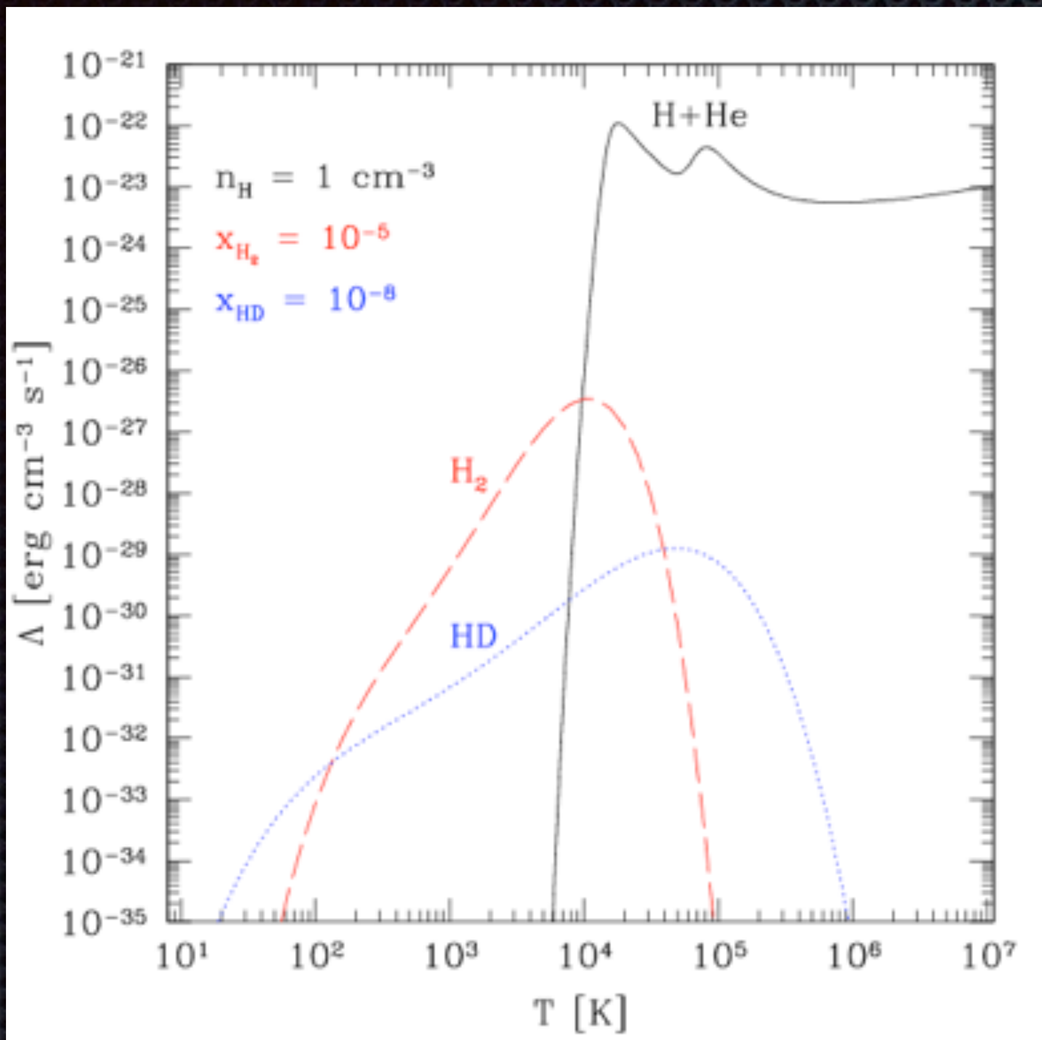
The First Billion Years Simulation (FiBY)

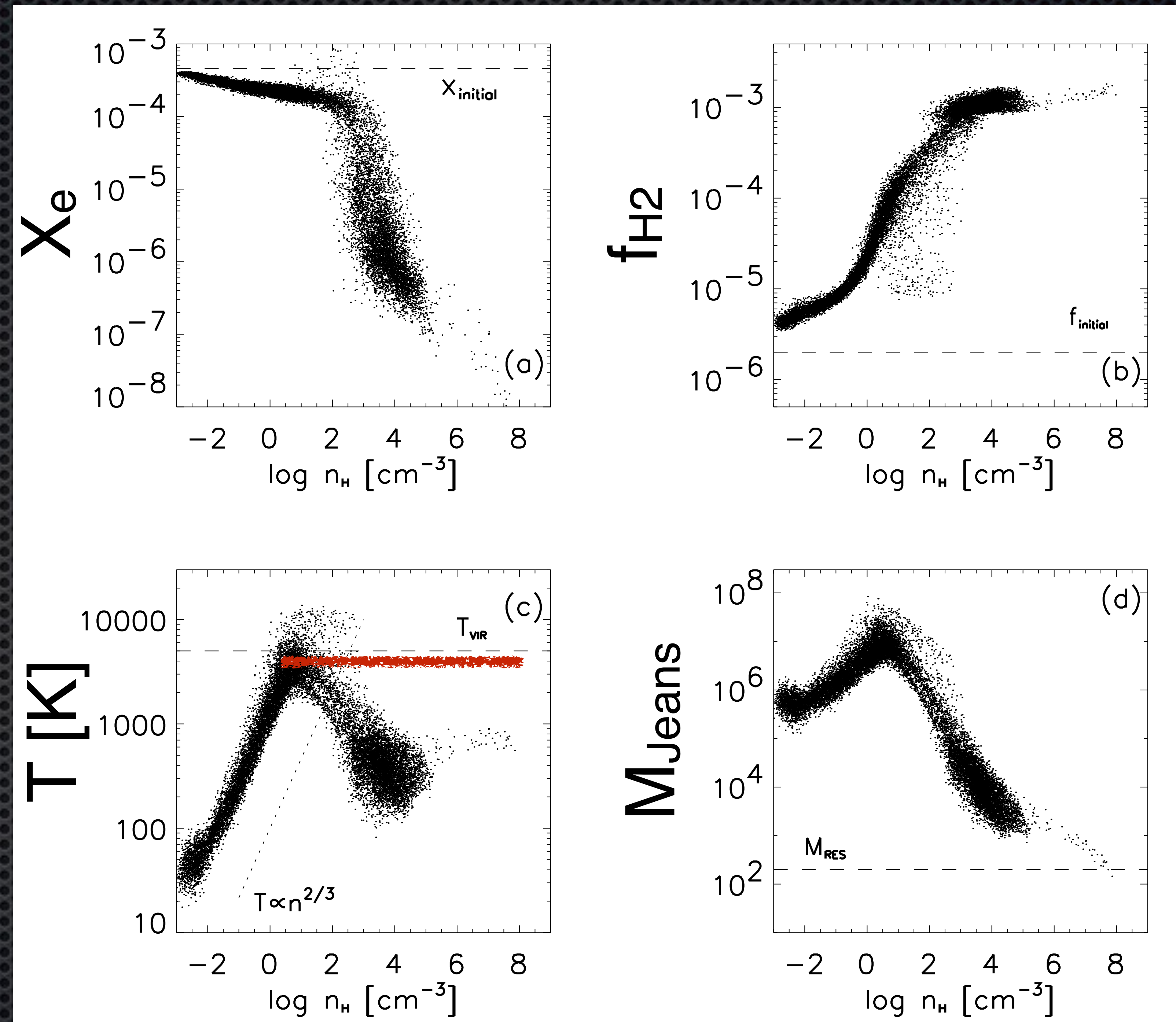
BH Seeds



Credit: D. Eastwood

DCBH Requirements





$$\dot{M}_{acc} \sim \frac{M_J}{t_{ff}} \propto T^{3/2}$$

For atomic cooling haloes:

$$\dot{M}_{acc} \sim \text{few } \mathrm{M}_{\odot}/\mathrm{yr}$$

Bromm et al. 2002

- **Atomic cooling halo, $T \sim 10^4$ K; metal free; no star; no molecules**

Lyman Werner Background

Atomic cooling halo, T~10^4 K; metal free; no star; no molecules

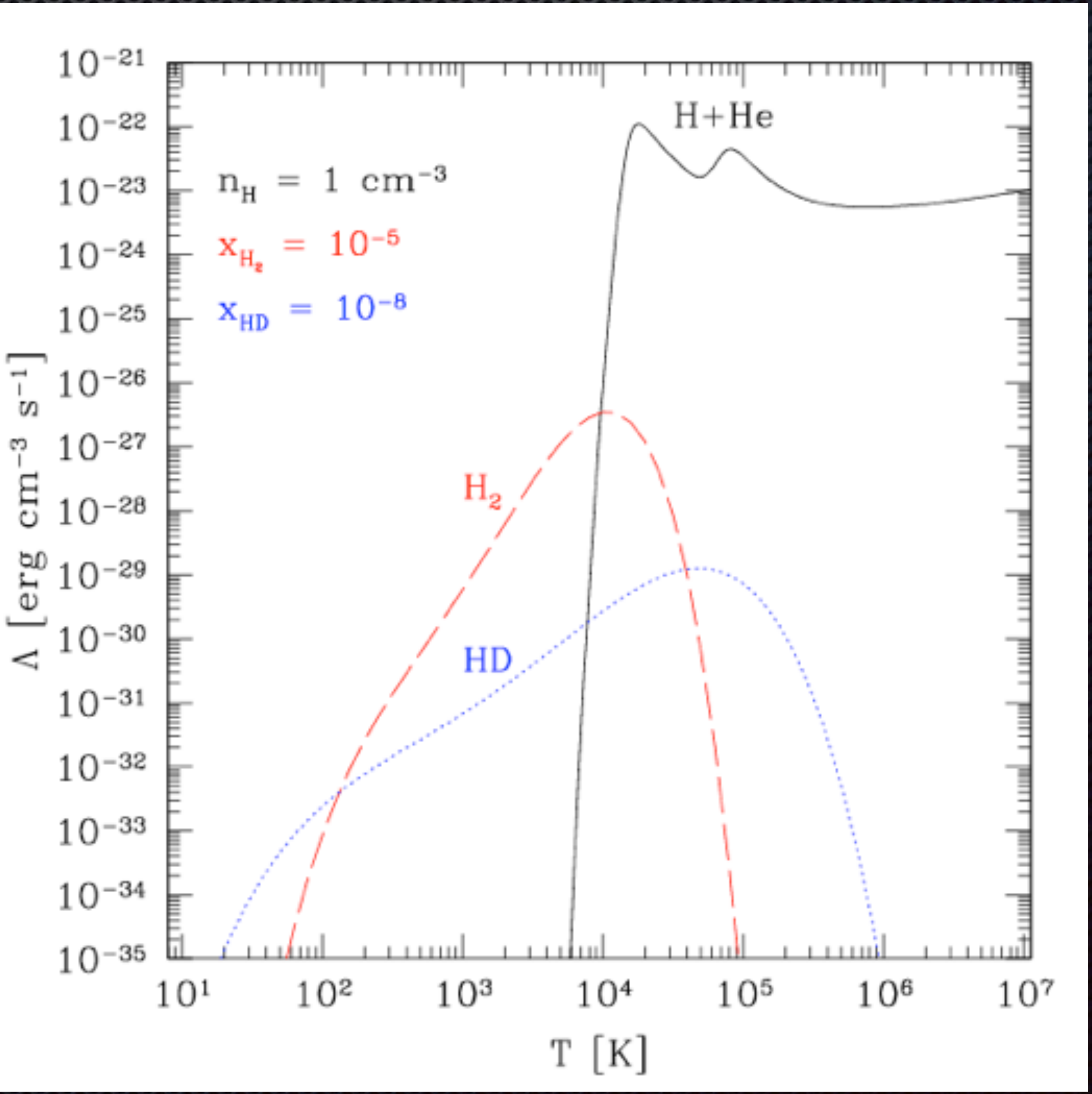
Main H_2 formation channel

$$H^- + H \rightarrow H_2^- \rightarrow H_2 + e^-$$

Photo-dissociation via LW radiation with 11.2-13.6 eV and photo-detachment with via radiation > 0.75 eV

$$H_2 + h\nu \rightarrow 2H$$

$$H^- + h\nu \rightarrow H + e^-$$



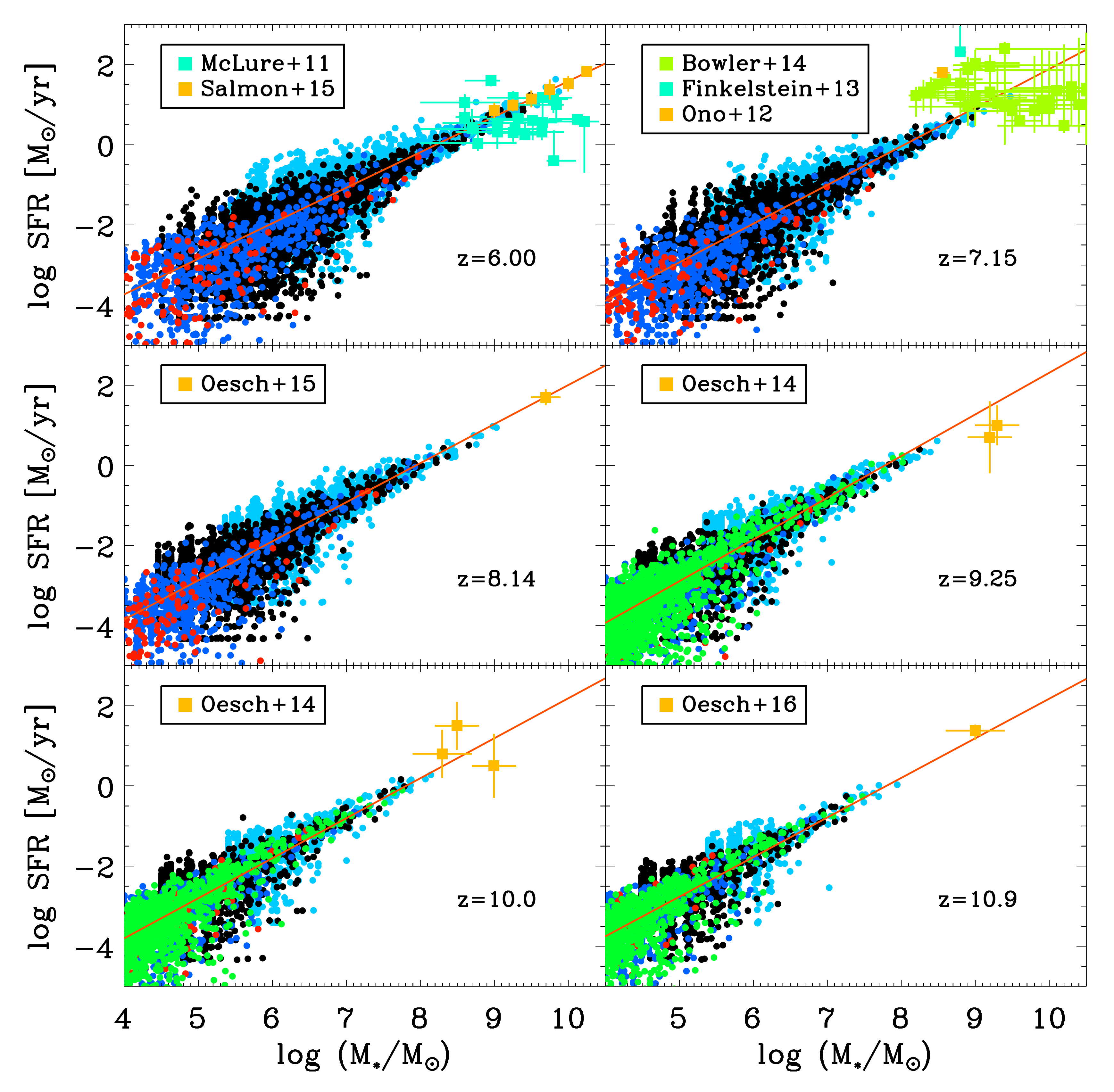
The FiBY Project

Reduce 'the mass gap' by following the formation of galaxies from primordial star formation in min-haloes to massive haloes during the first billion years of the Universe

- GADGET version used for the OWLS project (Schaye et al. 2010): SF; metal enrichment; metal line cooling from 11 elements; BH growth and feedback, thermal SN-feedback
- Added molecular networks and cooling from molecules
- Added POPIII formation, evolution, PISN; and yields; seed BHs
- Added dust from PISN, AGB & SNII; thermal sputtering
- Inclusion of Lyman-Werner background
- Self-shielding against radiation
- Coupled to radiative transfer scheme SIMPLEX (Paardekooper et al, 2013,2015)

$$V = (8\mathrm{Mpc})^3$$
$$N = 2 \times 1368^3$$
$$m_{gas} = 890 M_\odot h^{-1}$$
$$m_{DM} = 4375 M_\odot h^{-1}$$

SFR Main Sequence



Khochfar+16, in prep.

Lyman Werner Background

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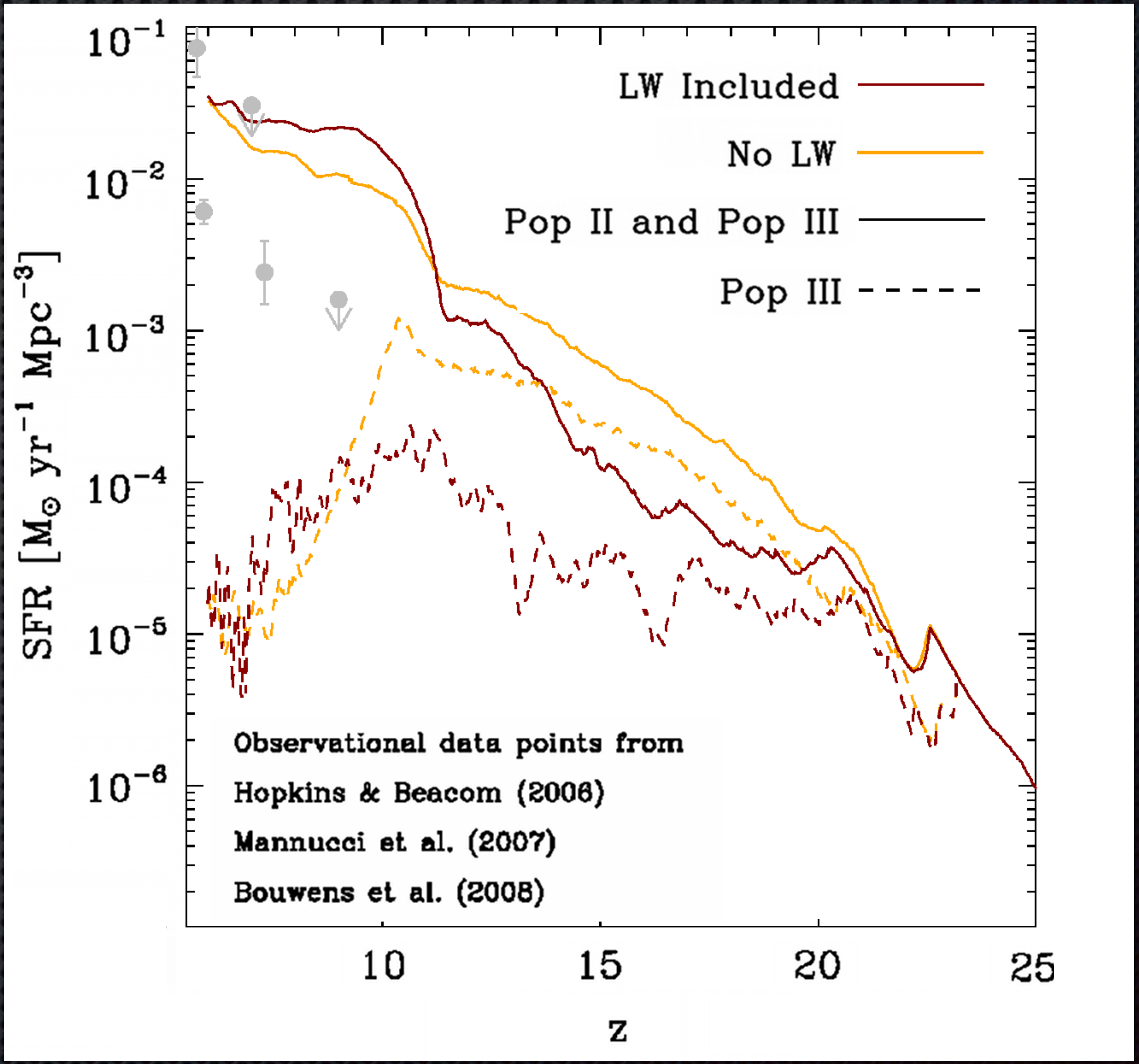
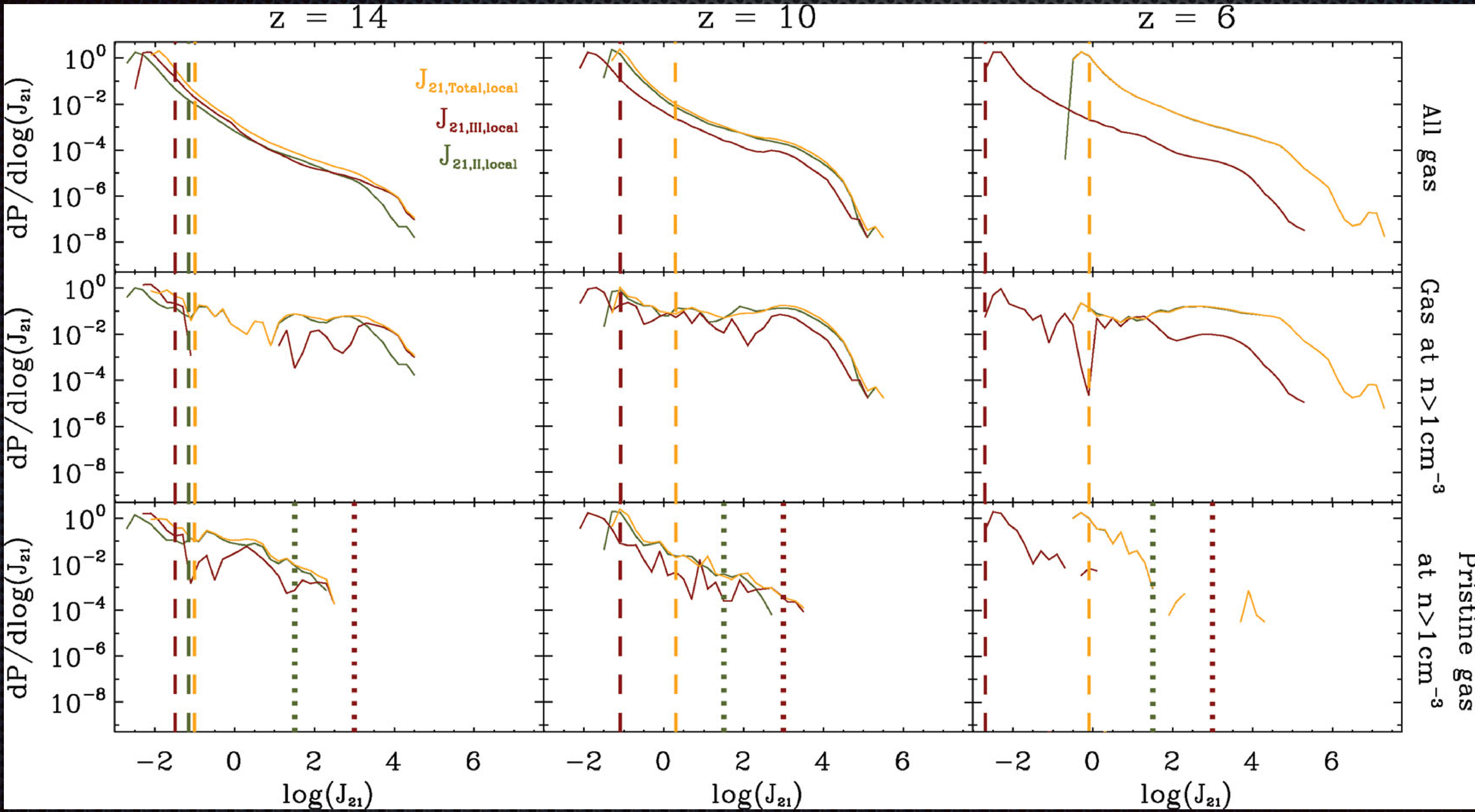
Include local self-shielding (Draine & Bertoldi 1996, Wolcott-Green et al 2011)



Johnson, Dalla Vecchia & SK 2013

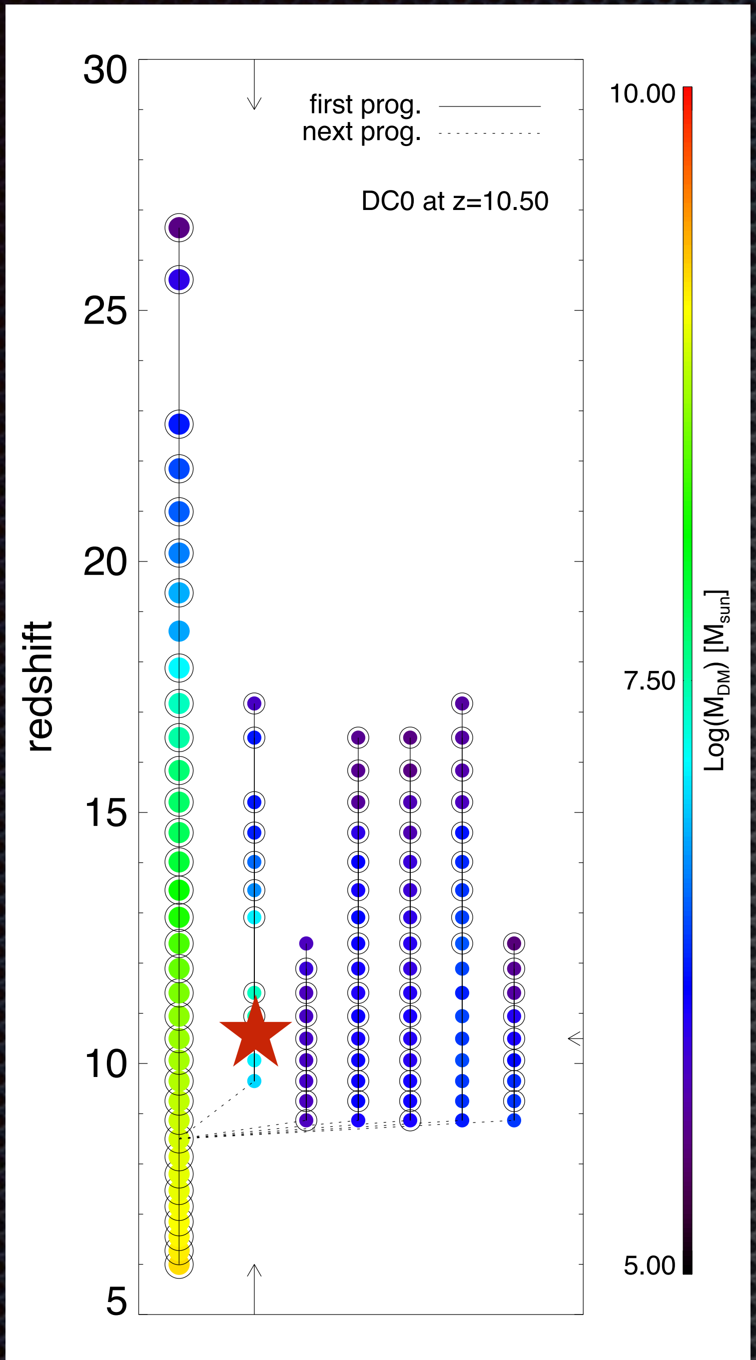
J_{LW} Levels

$J_{21}[10^{-21}\mathrm{erg\ s^{-1}cm^{-2}Hz^{-1}sr^{-1}}]$

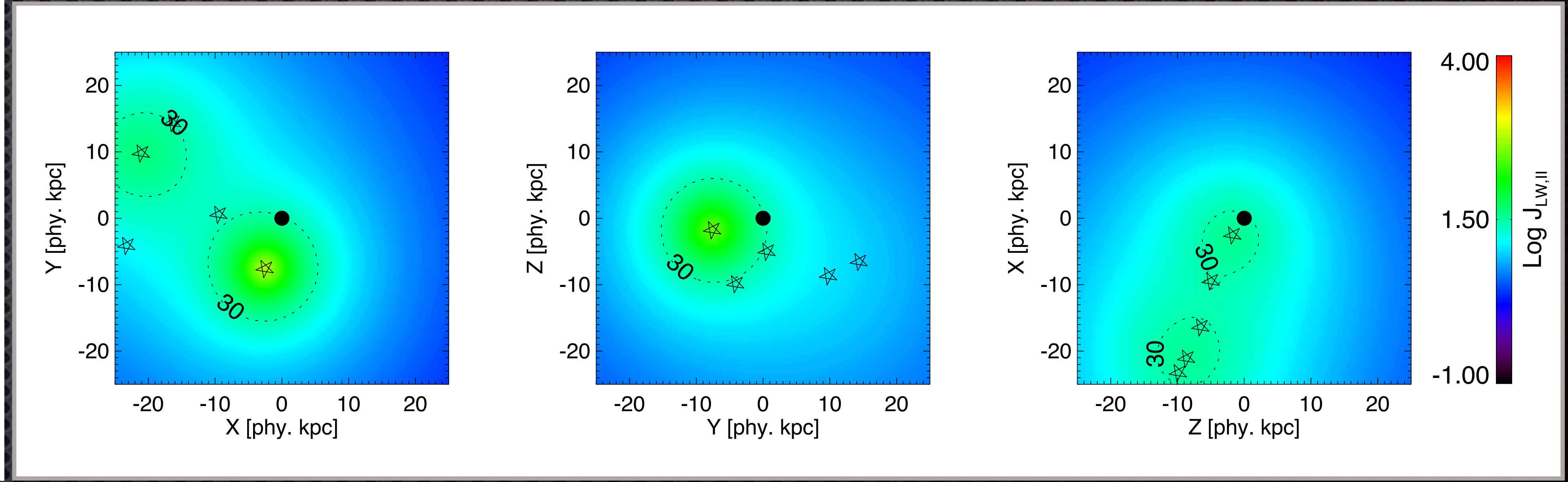


Johnson, Dalla Vecchia & SK 2013

Formation Sites



- Atomic cooling halo
- Metal free
- No star
- $J_{21} > 30$



Agarwal et al 2014

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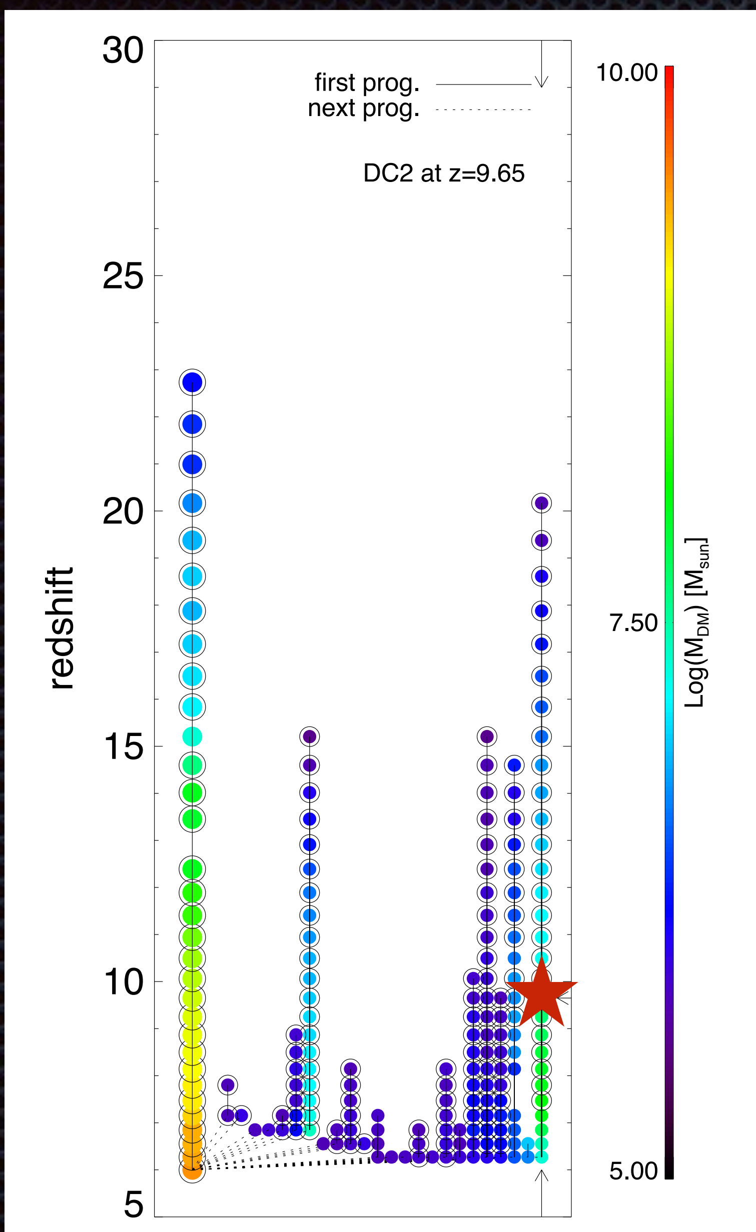
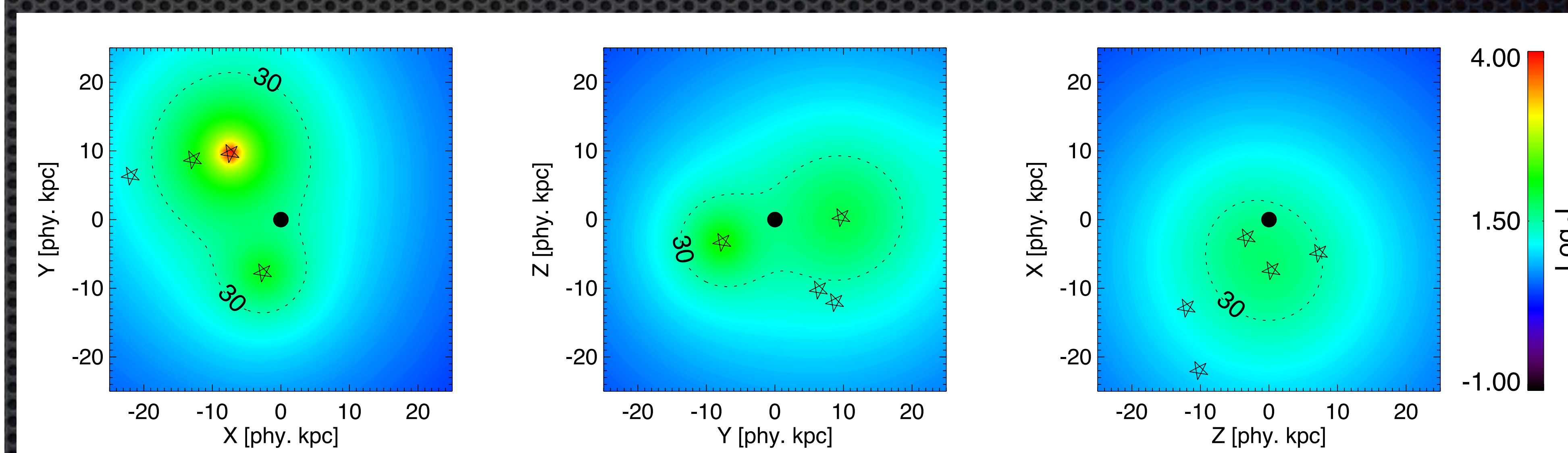
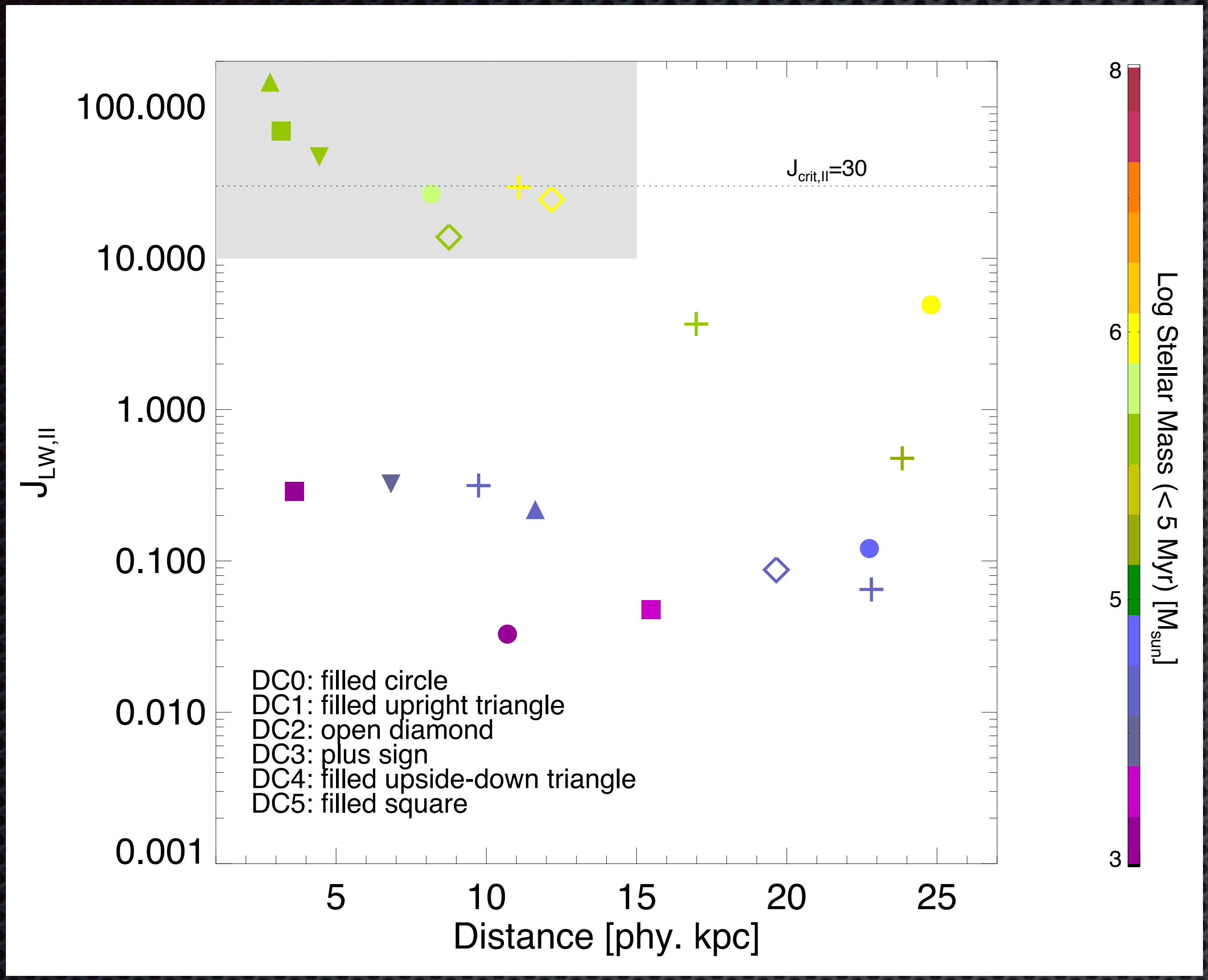
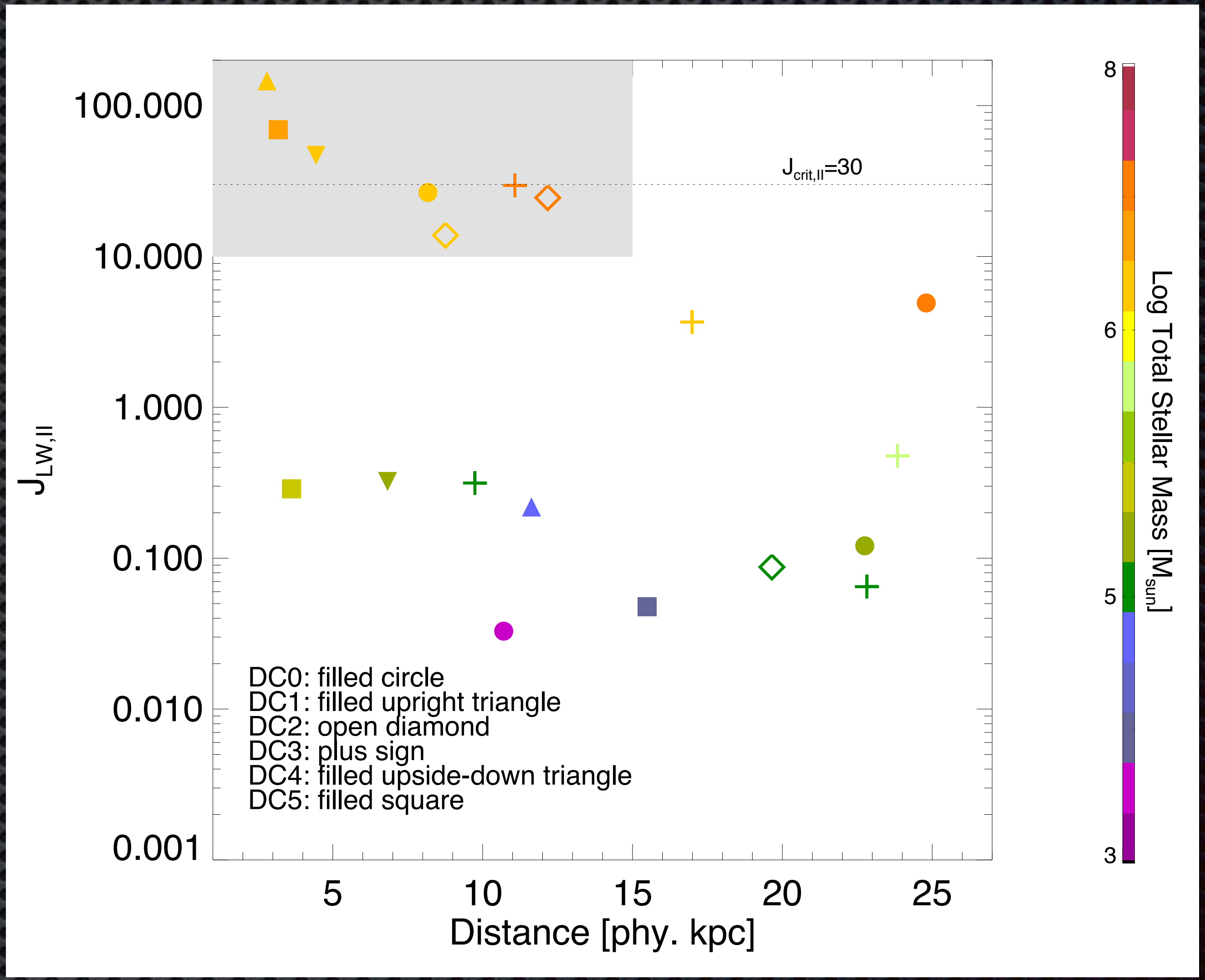




Agarwal et al 2014

Properties of Neighbours

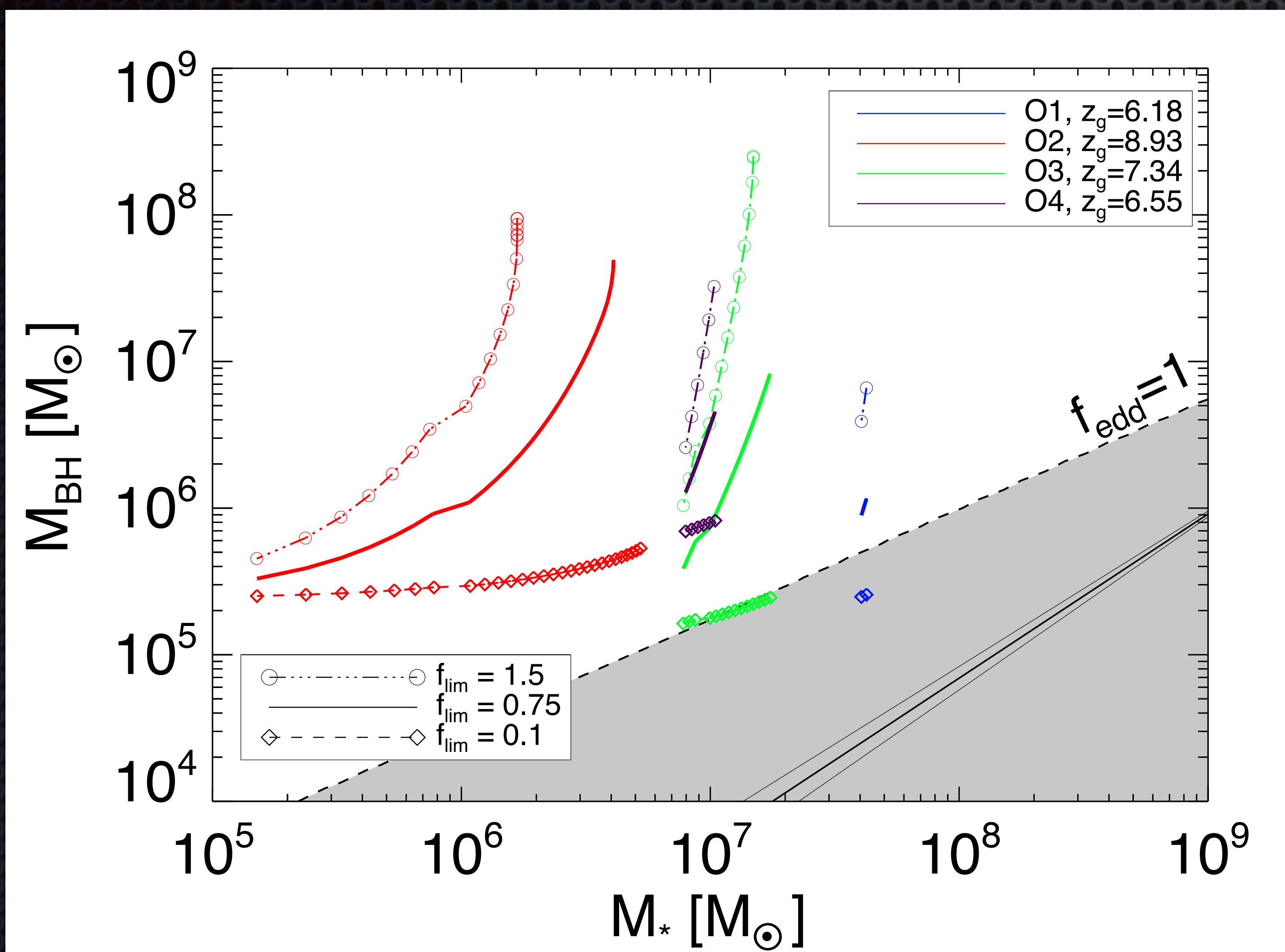




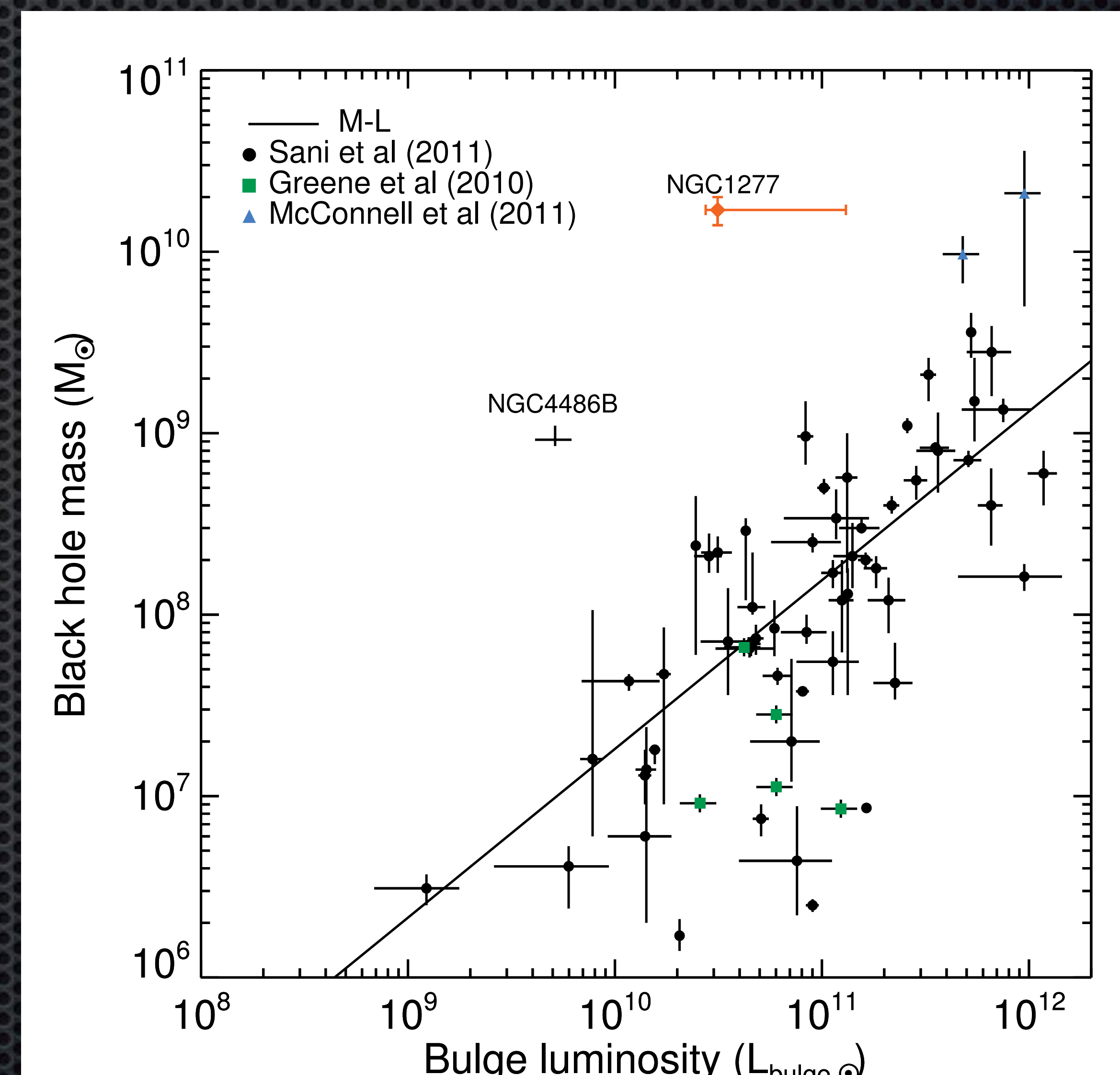
Agarwal et al 2014

Number density of potential DCBH sites: $\Phi \sim 1\mathrm{Mpc}^{-3}$

Obese Black Hole Galaxies (OBGs)



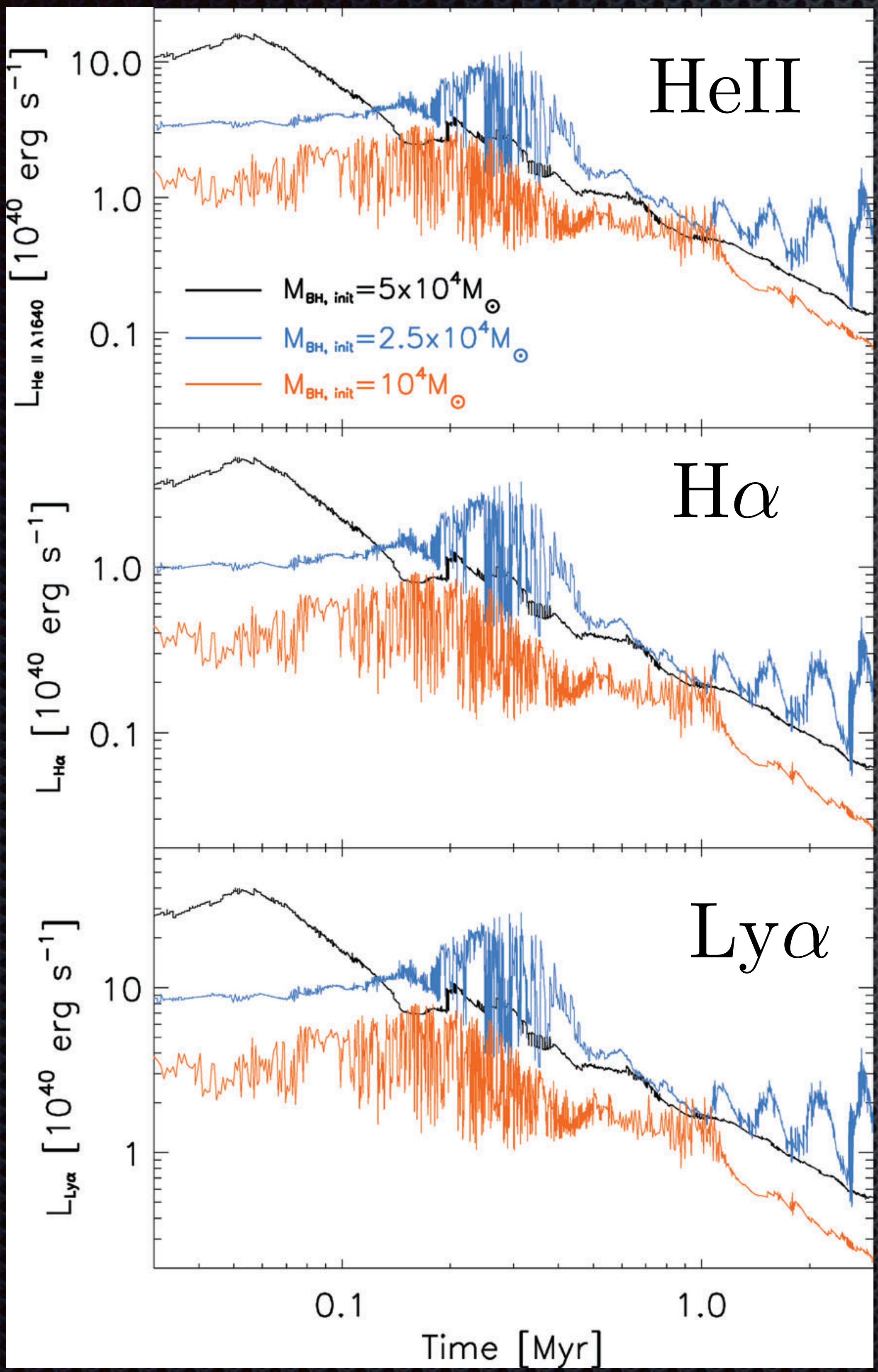
Agarwal et al 2013



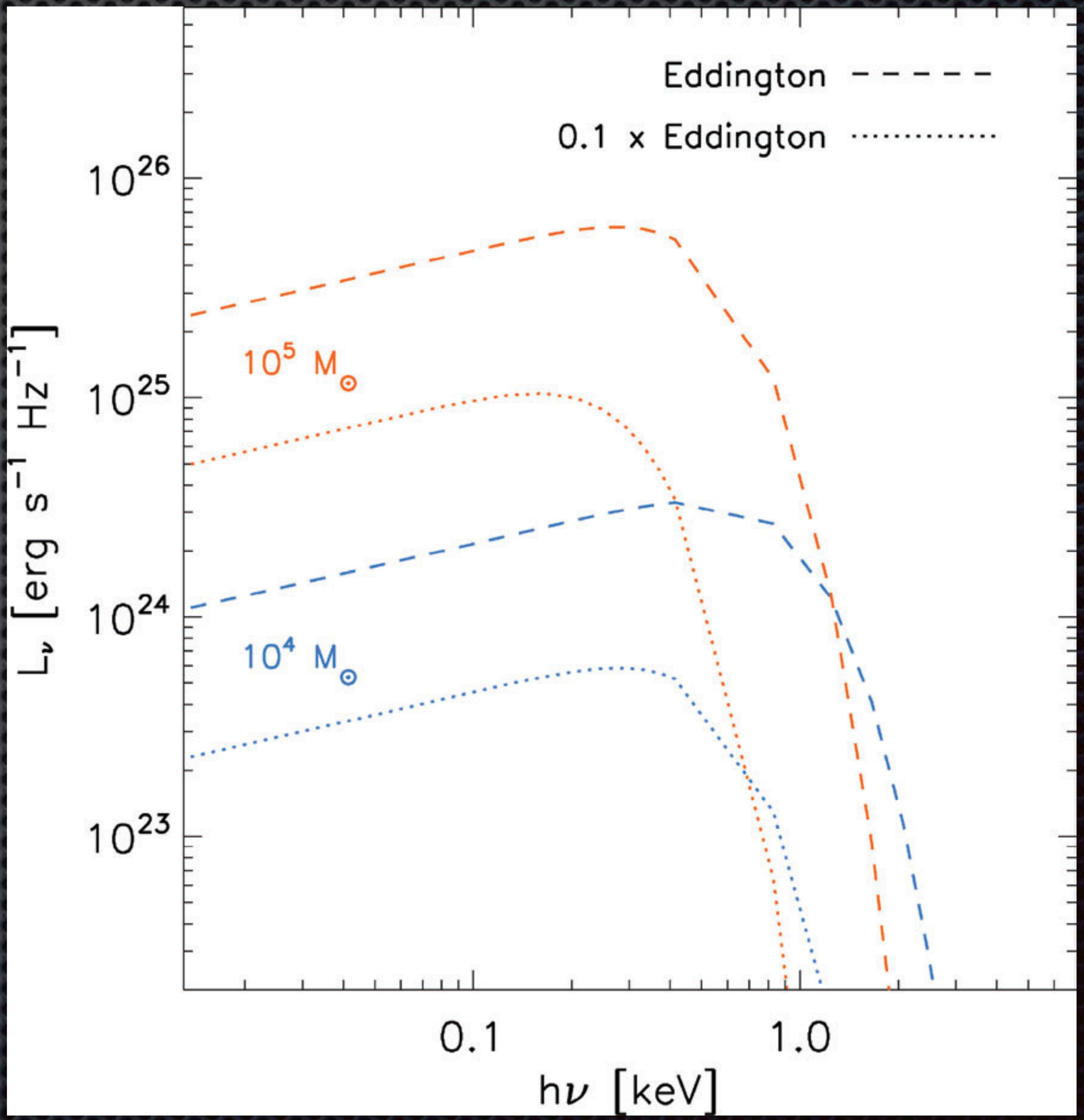
Van den Bosch et al 2013

Observational signature

Emission Lines



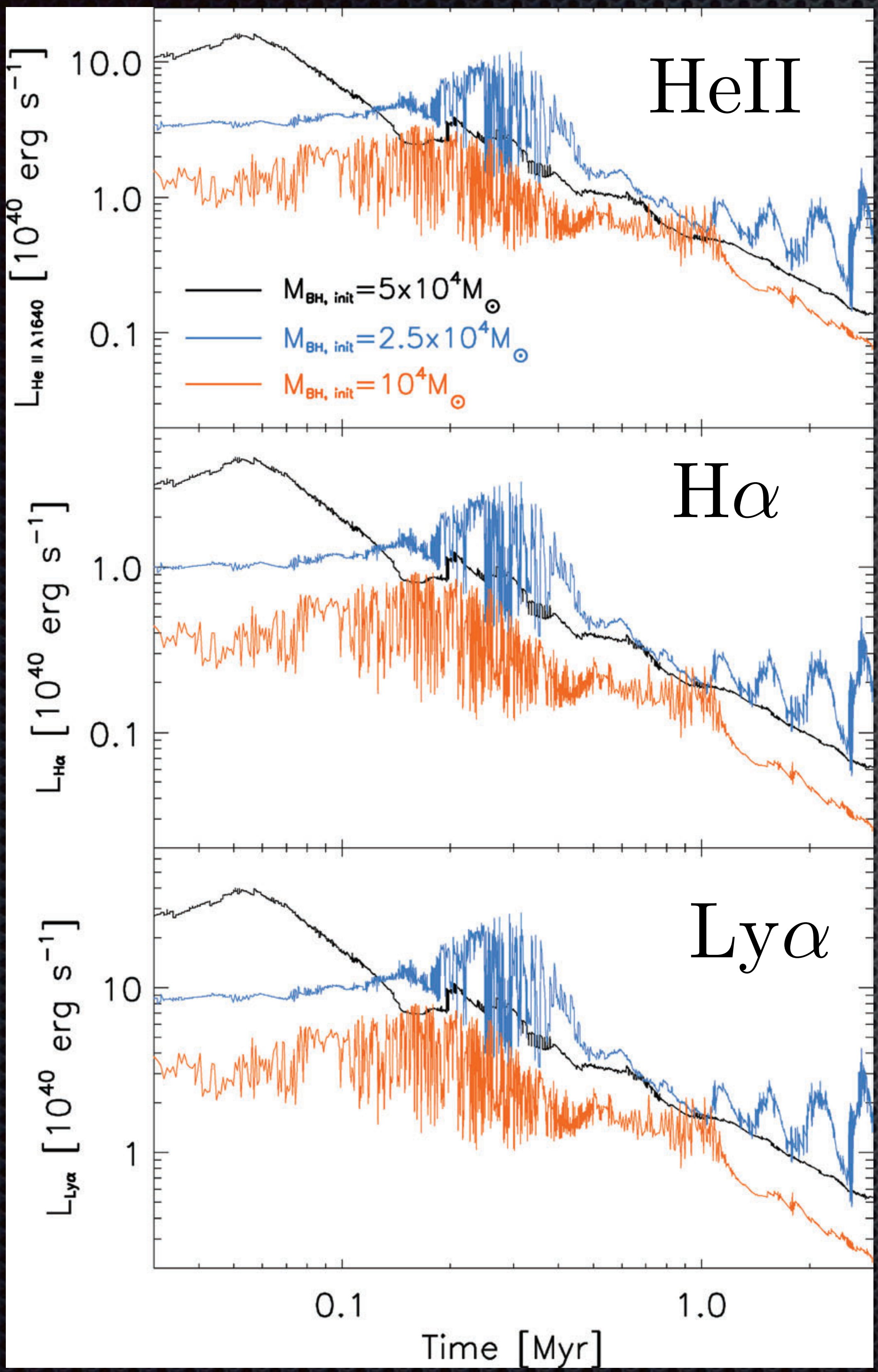
Multi-colour accretion disc



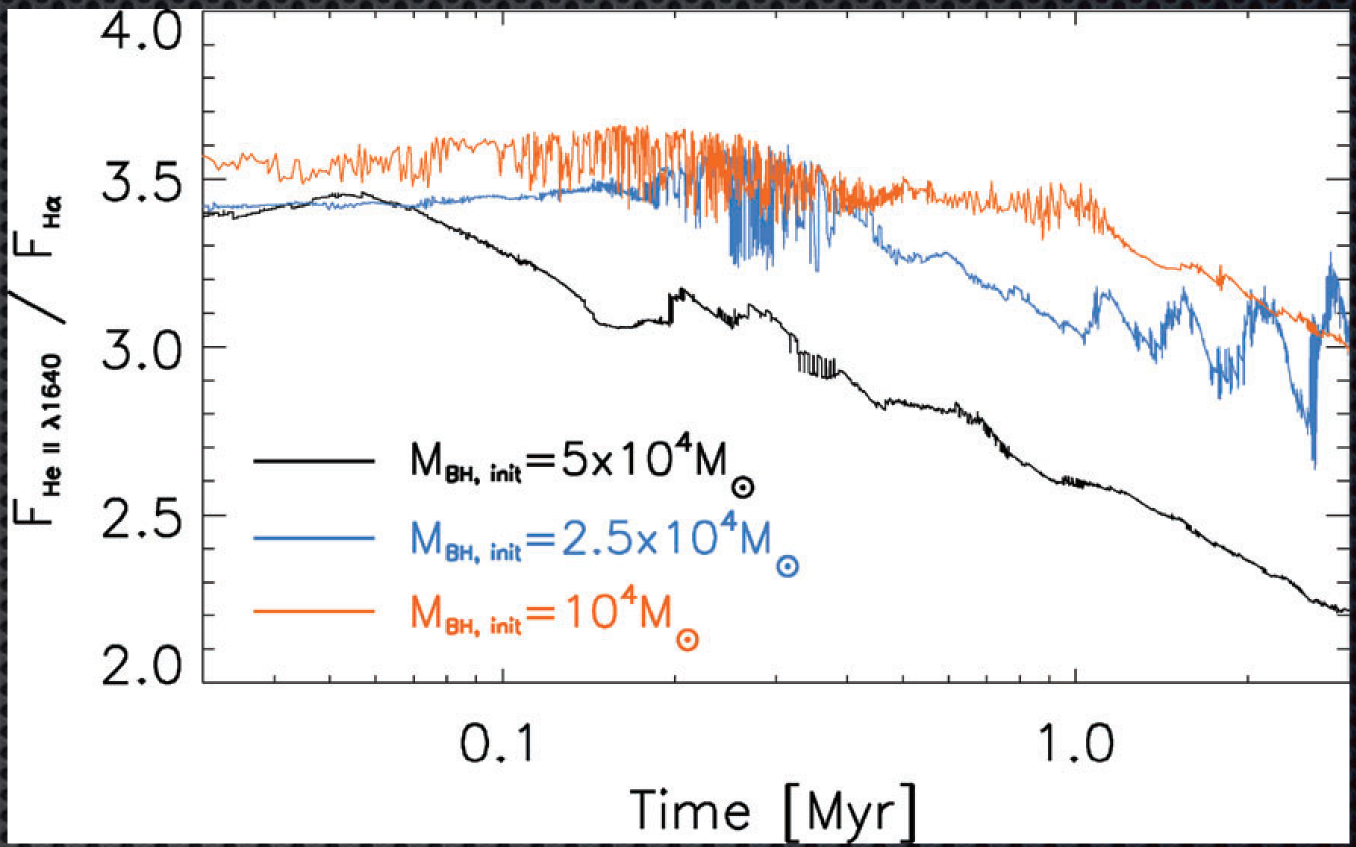
Johnson,SK+11

Observational signature

Emission Lines



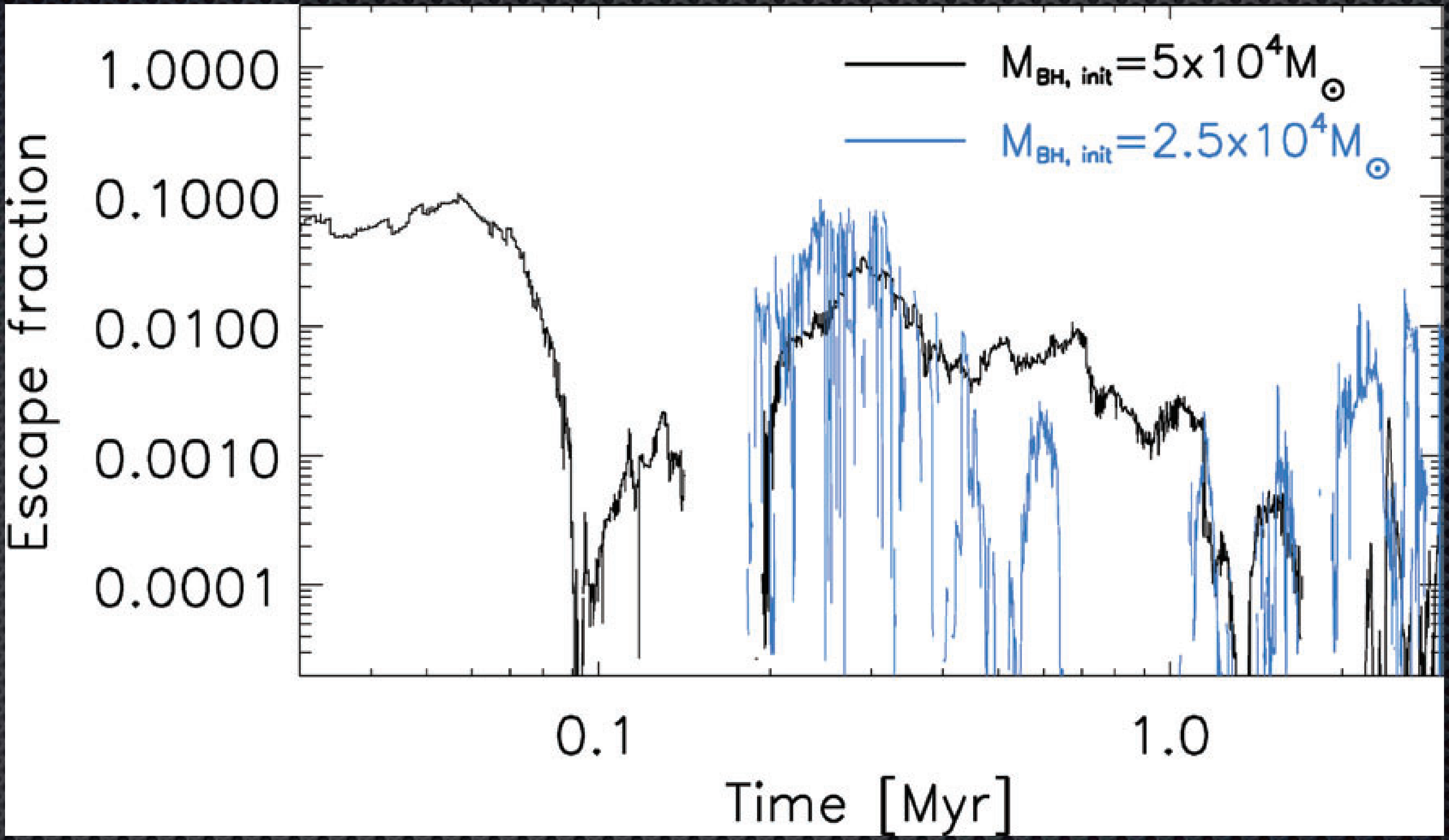
Ratio of HeII to H-alpha



Johnson,SK+11

POPIII stars have typically HeII/H-alpha fluxes < 2

Escape fraction



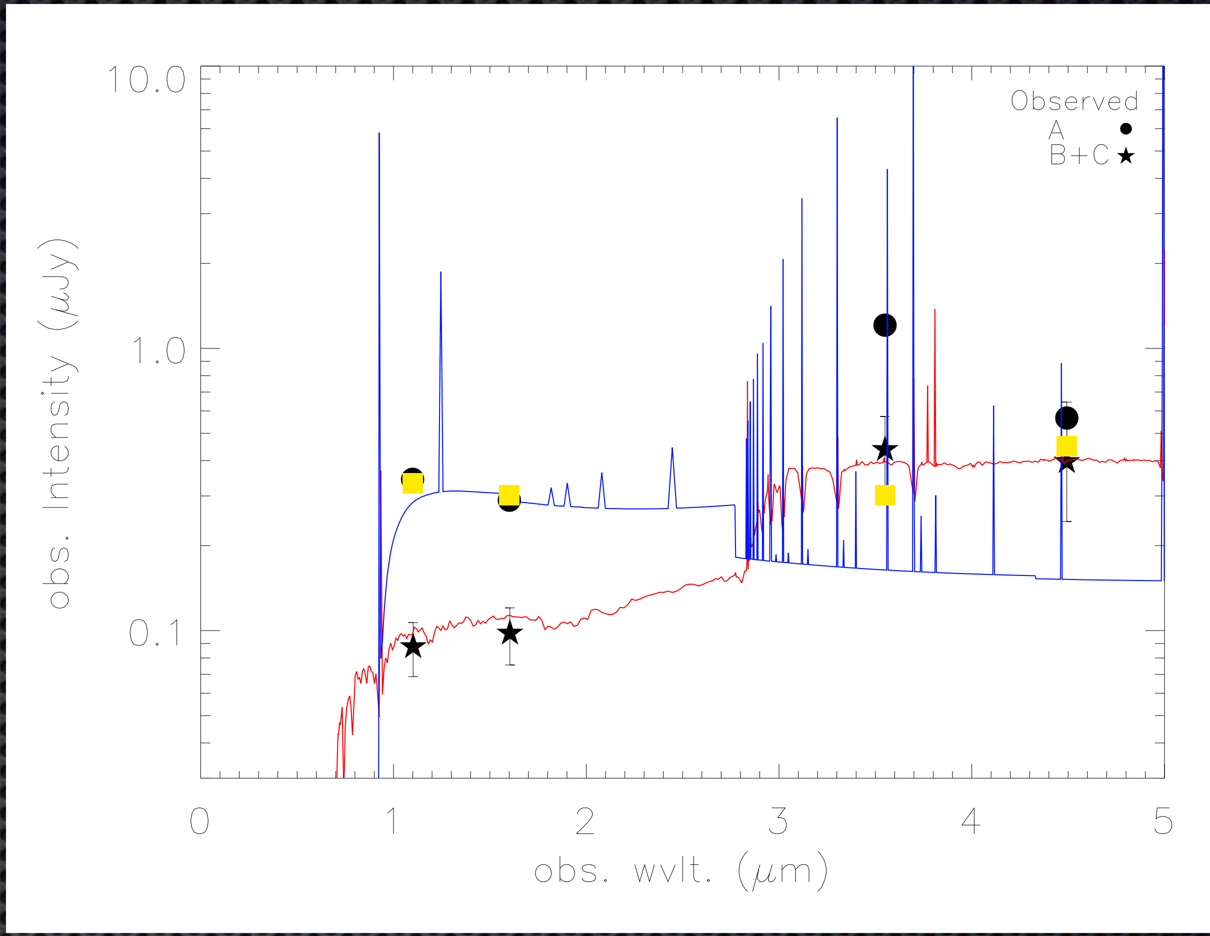
Johnson,SK+11

CR7

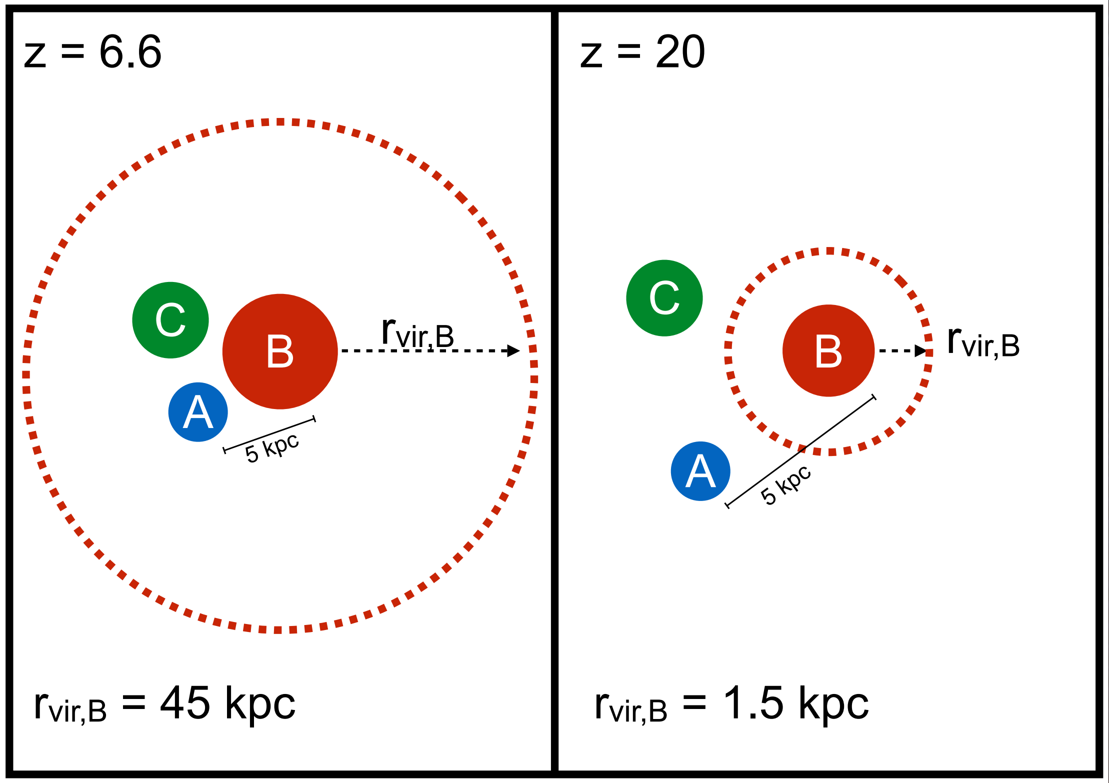
$$L_{\rm HeII} \sim 10^{43.26} {\rm erg/s}$$

$$L_{\rm Ly\alpha} \sim 10^{43.93} {\rm erg/s}$$

Sobral+15



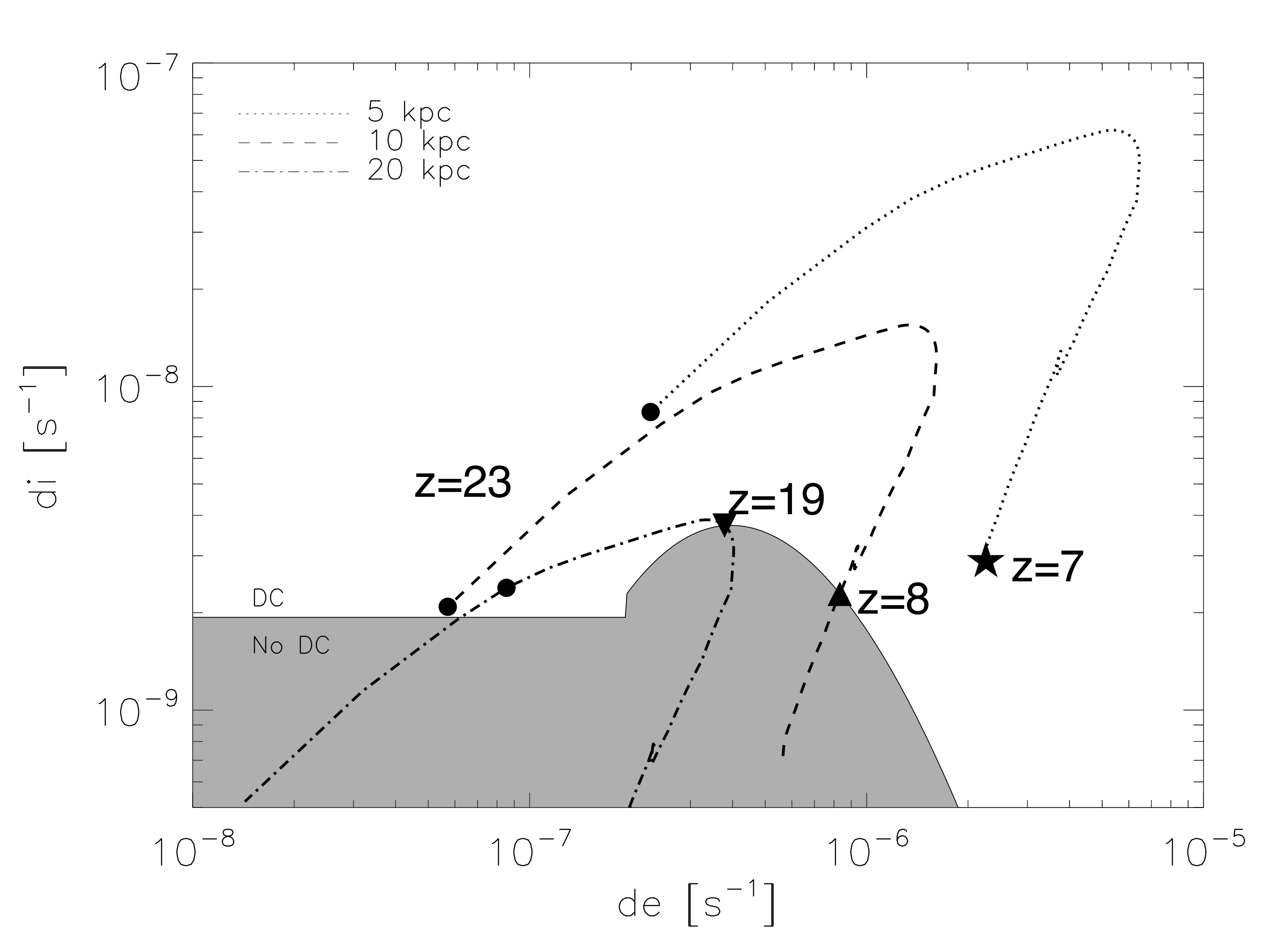
- B is fit with a 700 Myr old stellar population, with an exponentially decreasing [1] SFR from $z \approx 23 - 6.6$, such that at $z = 6.6$ it has a SFR of ~ 2 $\mathrm{M_\odot/yr}$ and $M_* = 2 \times 10^{10}$ $\mathrm{M_\odot}$
- C is fit with a 300 Myr old stellar population, with an exponentially decreasing SFR starting at $z \approx 9 - 6$, such that at $z = 6.6$ it has a SFR of ~ 1 $\mathrm{M_\odot/yr}$ and $M_* = 7 \times 10^{8}$ $\mathrm{M_\odot}$

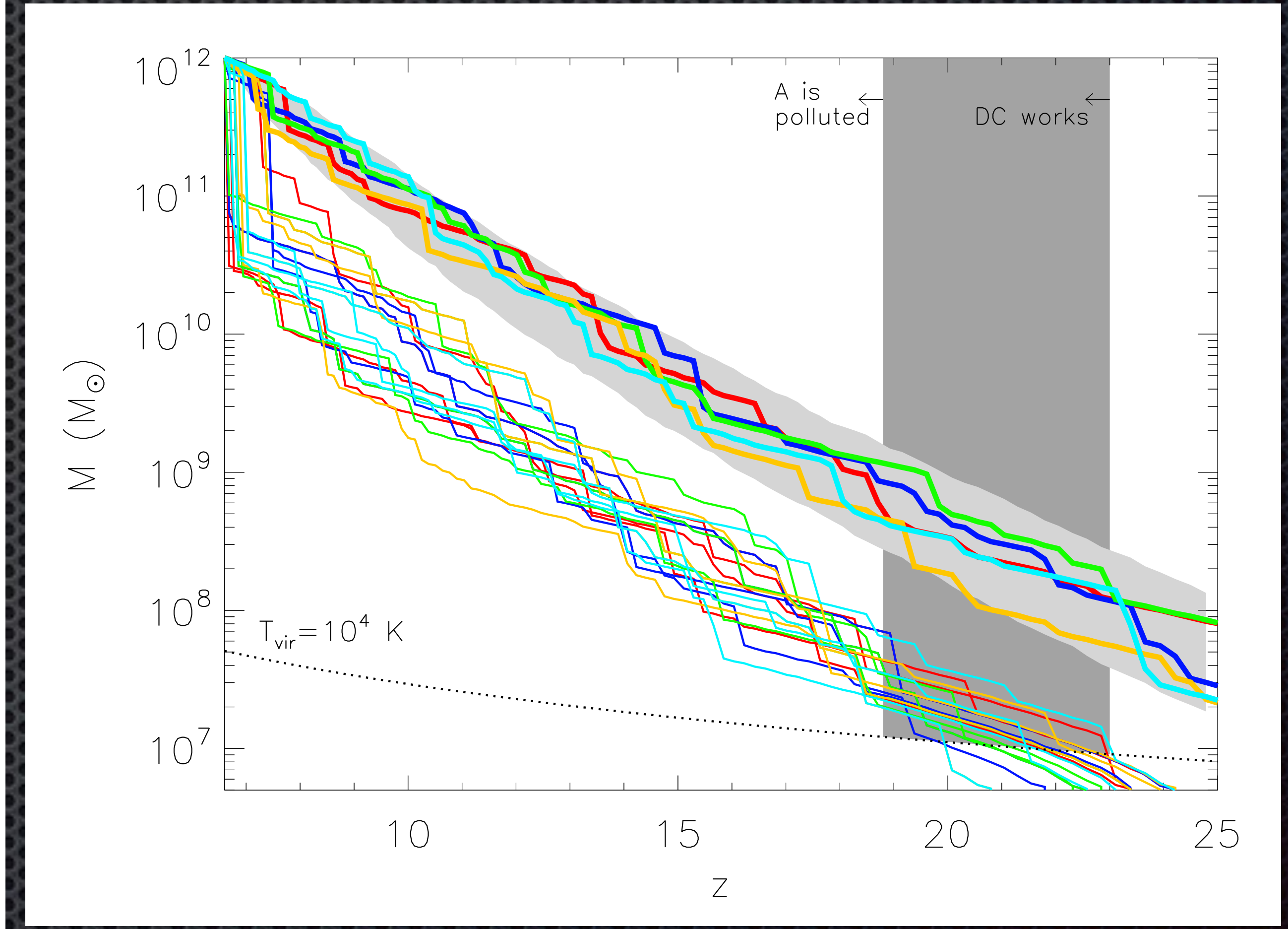


$$M_\bullet \sim 4.4 \times 10^{6} \mathrm{M_\odot}$$

Agarwal et al 2016

The right conditions to form a DCBH?





Agarwal et al 2016

Summary

- Local LW radiation is more important than global background
- DCBHs form close to one galaxy with distance < 15 Kpc that dominants the LW radiation, and merge with it later.
- Number densities are <1 Mpc^{-3} at z~6
- DCBHs start as OBGs and move toward the local M_{BH}-M_{bulge} relation via mergers
- DCBH should have HeII/H-alpha fluxes > 2 while growing
- The escape fraction form DCBHs is low < 0.1
- CR7 could host a DCBH based on the SFHs of system B+C