DIRECT COLLAPSE BLACK HOLES AS SEEDS OF QUASARS AT REDSHIFT > 6

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PROBLEM

- Explain supermassive black holes at z>6 (Fan et al., Mortlock et al., etc.)
- Structure: stars/galaxies/BHs only had 800 Myr to evolve (Tegnermark et al. 97)
- Cosmic Variance to the rescue?
- A scenario that does not depend on Cosmic Variance

OUTLINE

- Introduction

- Part I
  Semi-analytical model (Agarwal et al. 2012)

- Part II
  FiBY simulation (Agarwal et al. 2014)

  → Existence

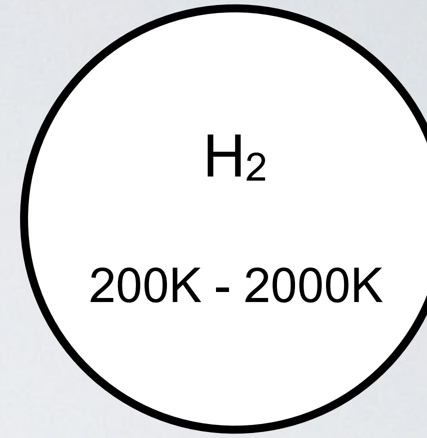
- Part III
  A new class of galaxies? (Agarwal et al. 2013) —— Evolution

- Summary

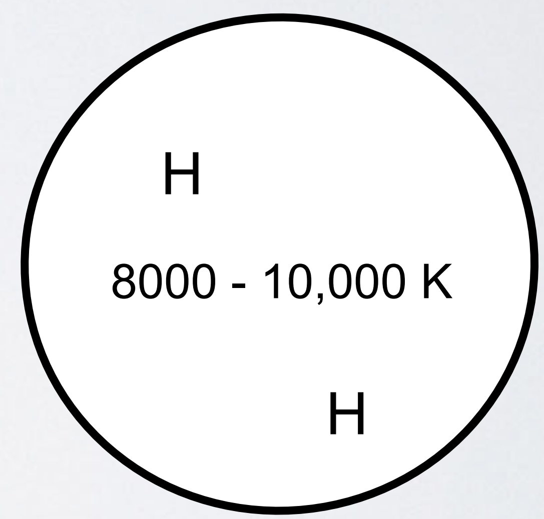
FIRST STARS AND GALAXIES

- First Stars and Galaxies
  $z \sim 20$-30, $t \sim 200$ Myr
- First Generation of stars
  Population III: 40-100 M_{sun}
- *First* stellar black holes: ~100 M_{sun}
  $t \sim 650$ Myr to grow from 10^2 to 10^9 M_{sun}

Requires:
- constant accretion at $f_{edd} = 1$
- massive gas reservoir
- Cosmic variance to the rescue!



$T_{vir} < 10{,}000$ K
Typical Mass: 10^6 M_{sun}



$T_{vir} > 10{,}000$ K
Typical Mass: 10^7 M_{sun}

MAKING THE FIRST STAR

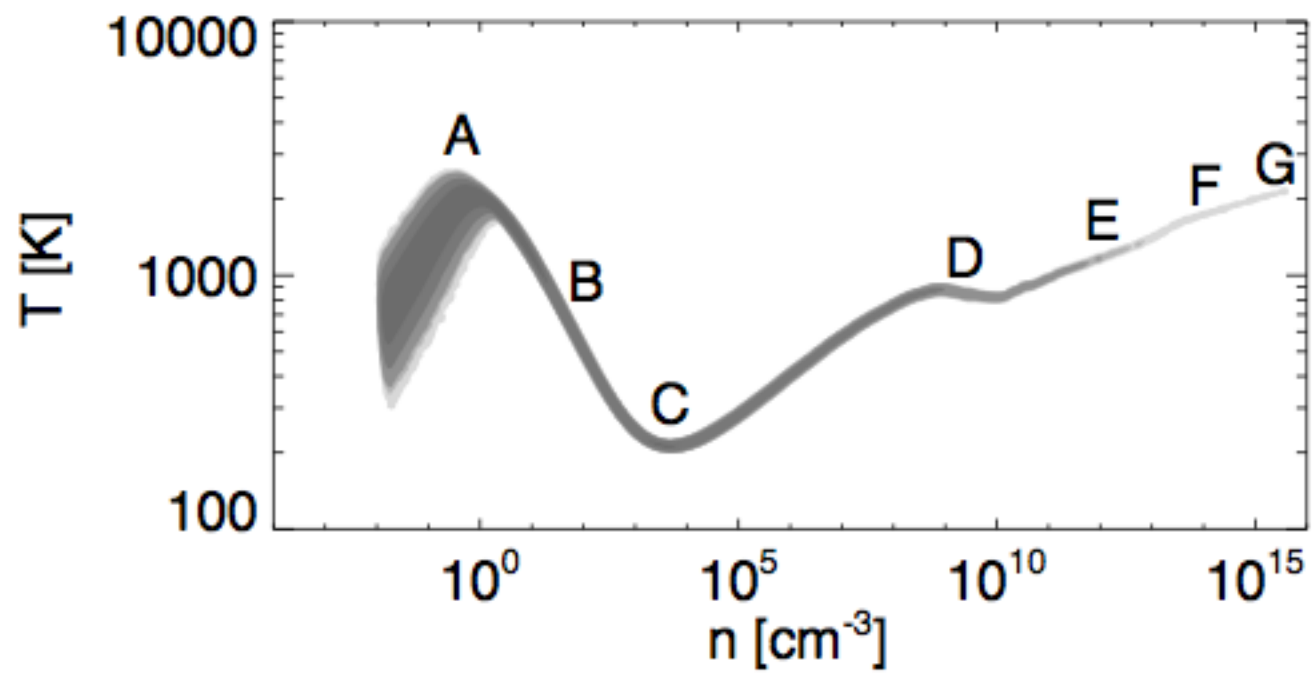


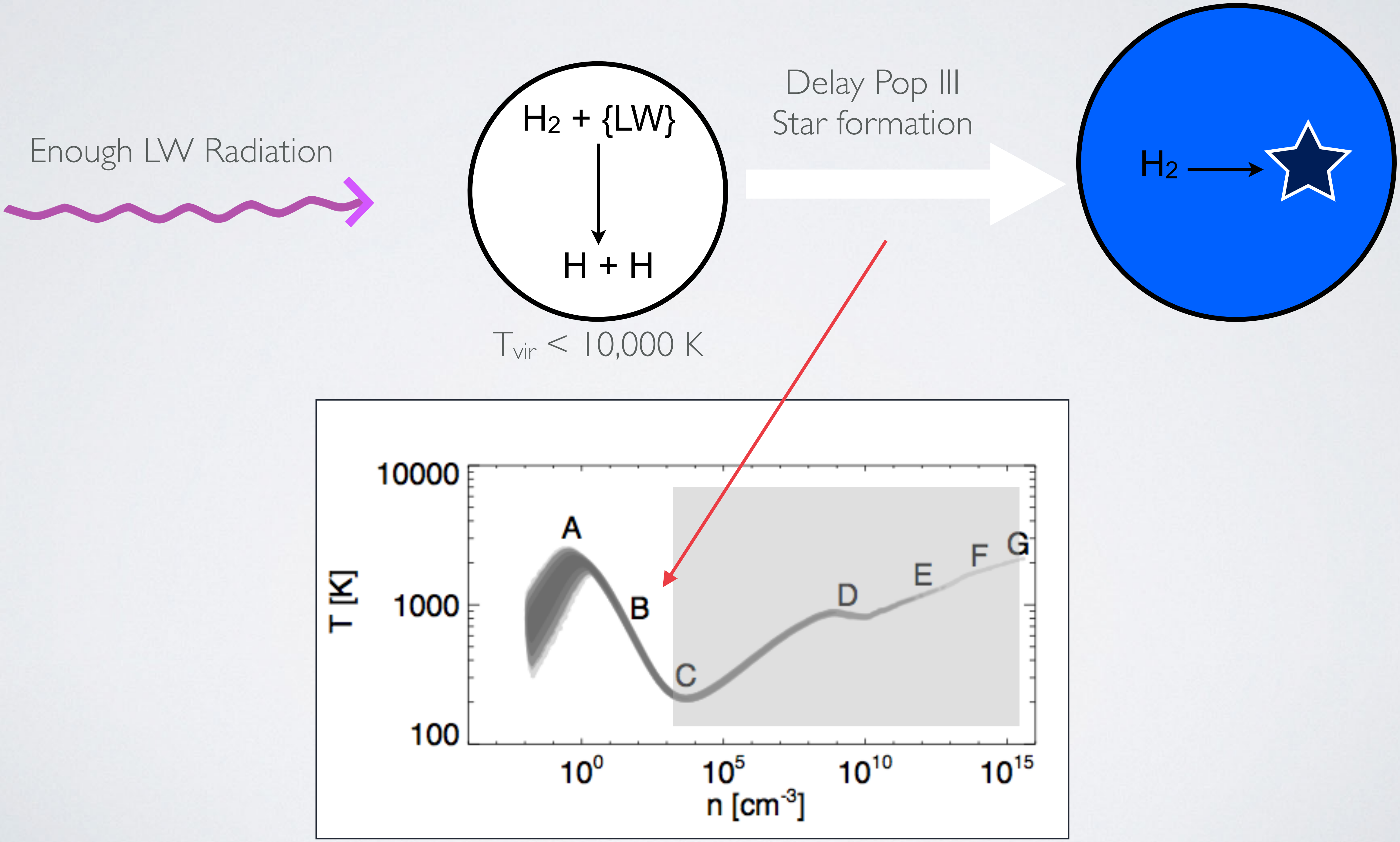
Figure 2.4: The density vs. temperature of pristine gas undergoing spherical collapse (taken from Yoshida et al., 2006). (A) gas is shock heated to the virial temperature and H_2 forms by two-body processes; (B) gas cools down to 200 K due to H_2 cooling; (C) H_2 cooling rate saturates and reaches the LTE value; (D) onset of three-body reactions, leading to the gas becoming fully molecular; (E) the line cooling becomes inefficient because of the high optical depth as the density of the gas increases; (F) collision-induced emission dominates cooling process; and (G) onset of H_2 dissociation at $T \sim 2000$ K.

LYMAN WERNER RADIATION

LW: 11.2 - 13.6 eV

Dissociate H_2 molecules: basic constituents of first galaxies/halo

J or J_{LW} in units: 10^{-21} erg/ s/ Hz/ cm^2/ sr



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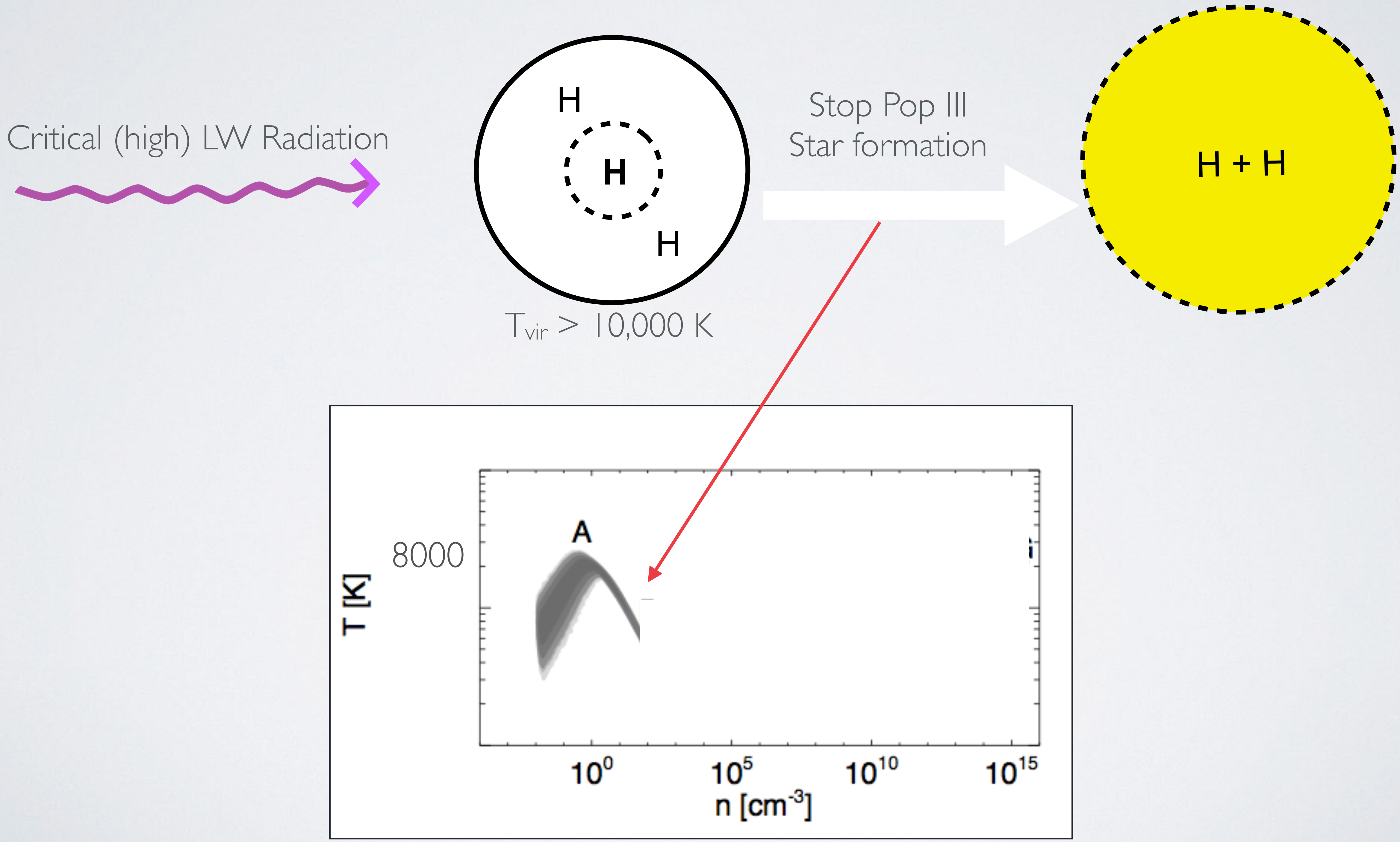


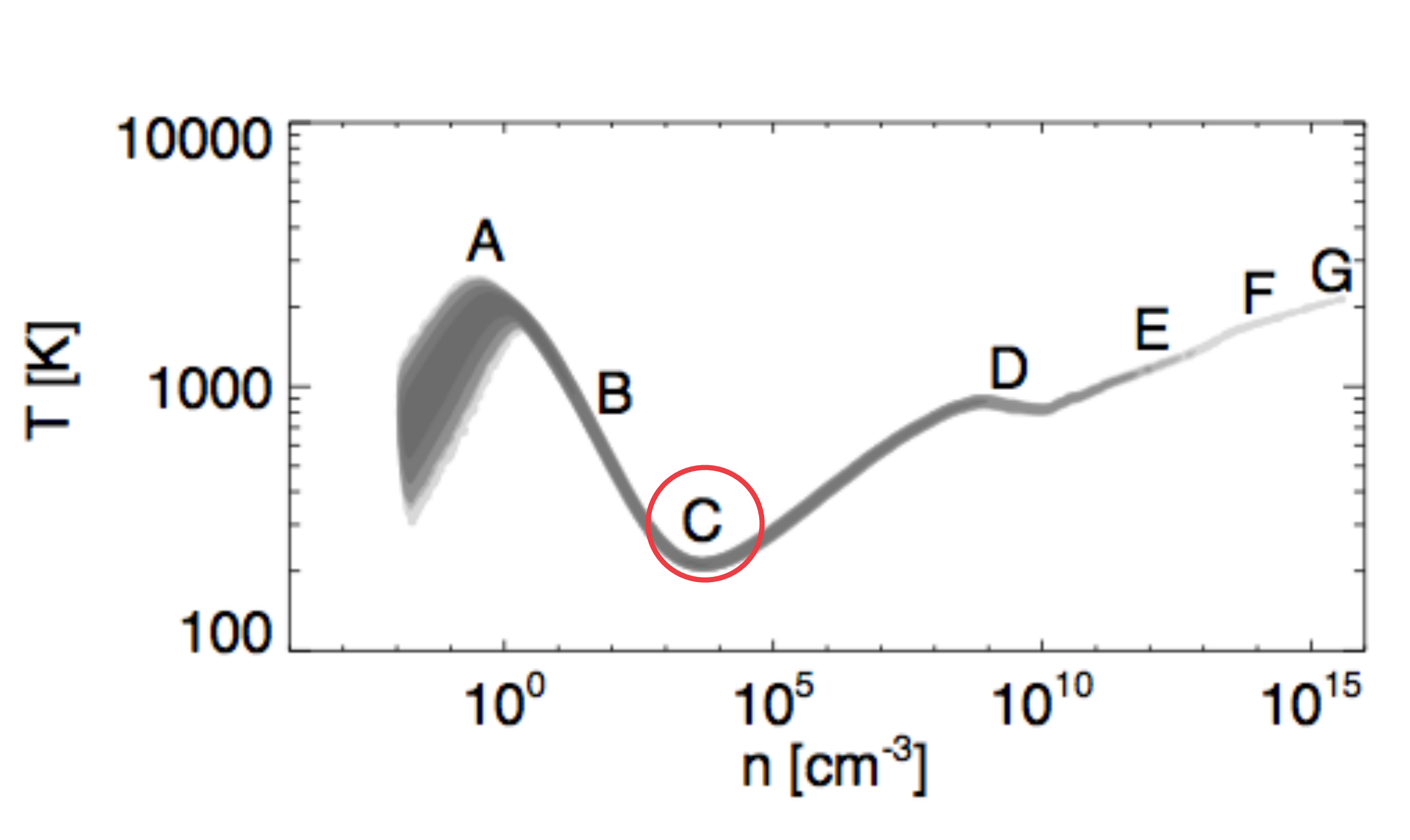
MAKING A DCBH

$$M_J = \frac{4}{3}\pi\lambda_J^3\rho = \frac{\pi^{\frac{5}{2}} c_s^3}{6\ G^{\frac{3}{2}}\sqrt{\rho}}$$

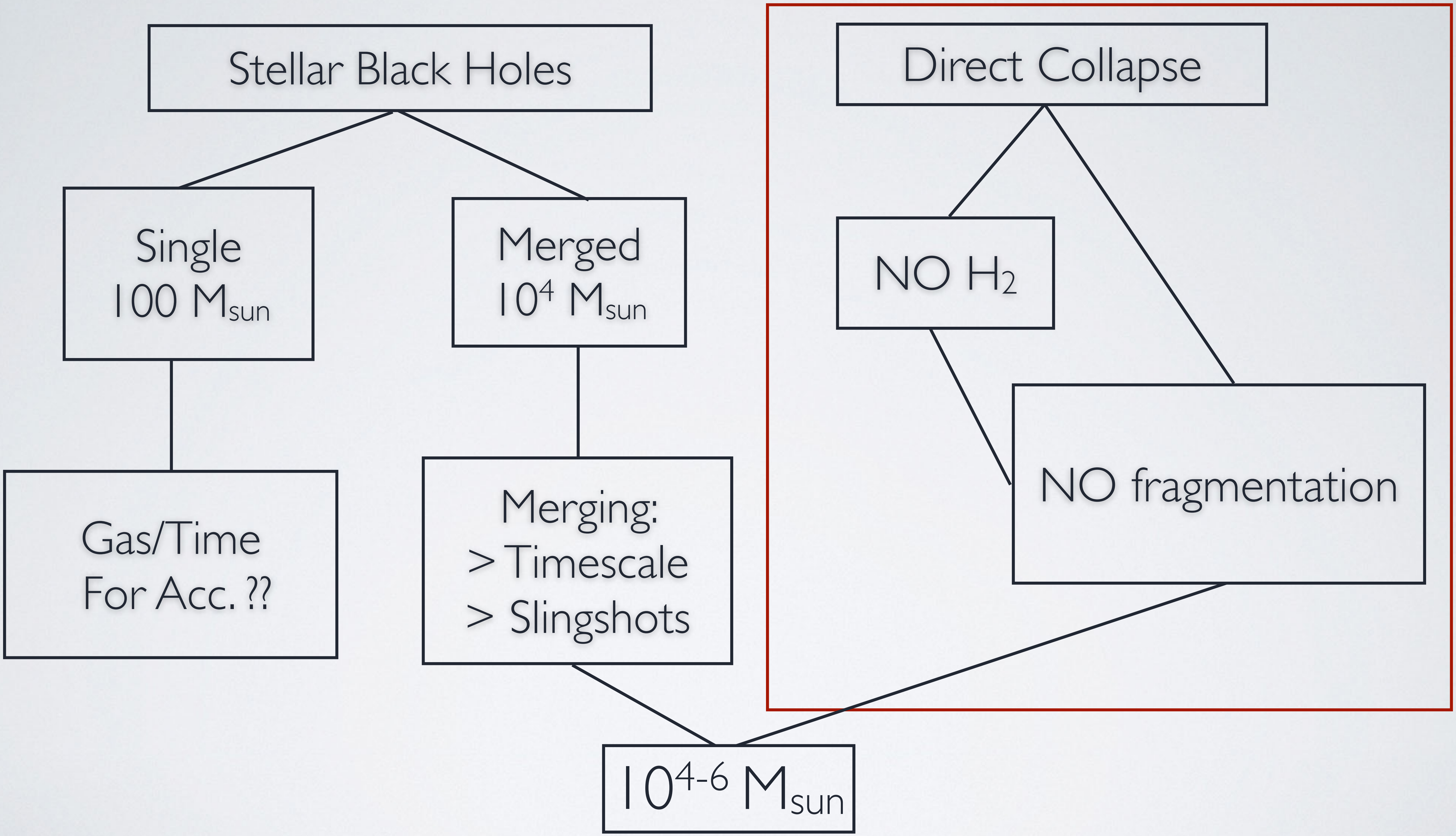
$$\frac{M_{BE}}{\mathrm{M}_\odot} = 40\ T^{\frac{3}{2}} n^{-\frac{1}{2}}$$

- Pop III
  $n = 10^5\ cm^3$
  $T = 200$ K
- $M_{BE} \sim 100\ M_{sun}$

- DCBH
  $n = 10^5\ cm^3$
  $T = 8000$ K
- **$M_{BE} \sim 10^5\ M_{sun}$**



CREATING SMBH BY Z=6

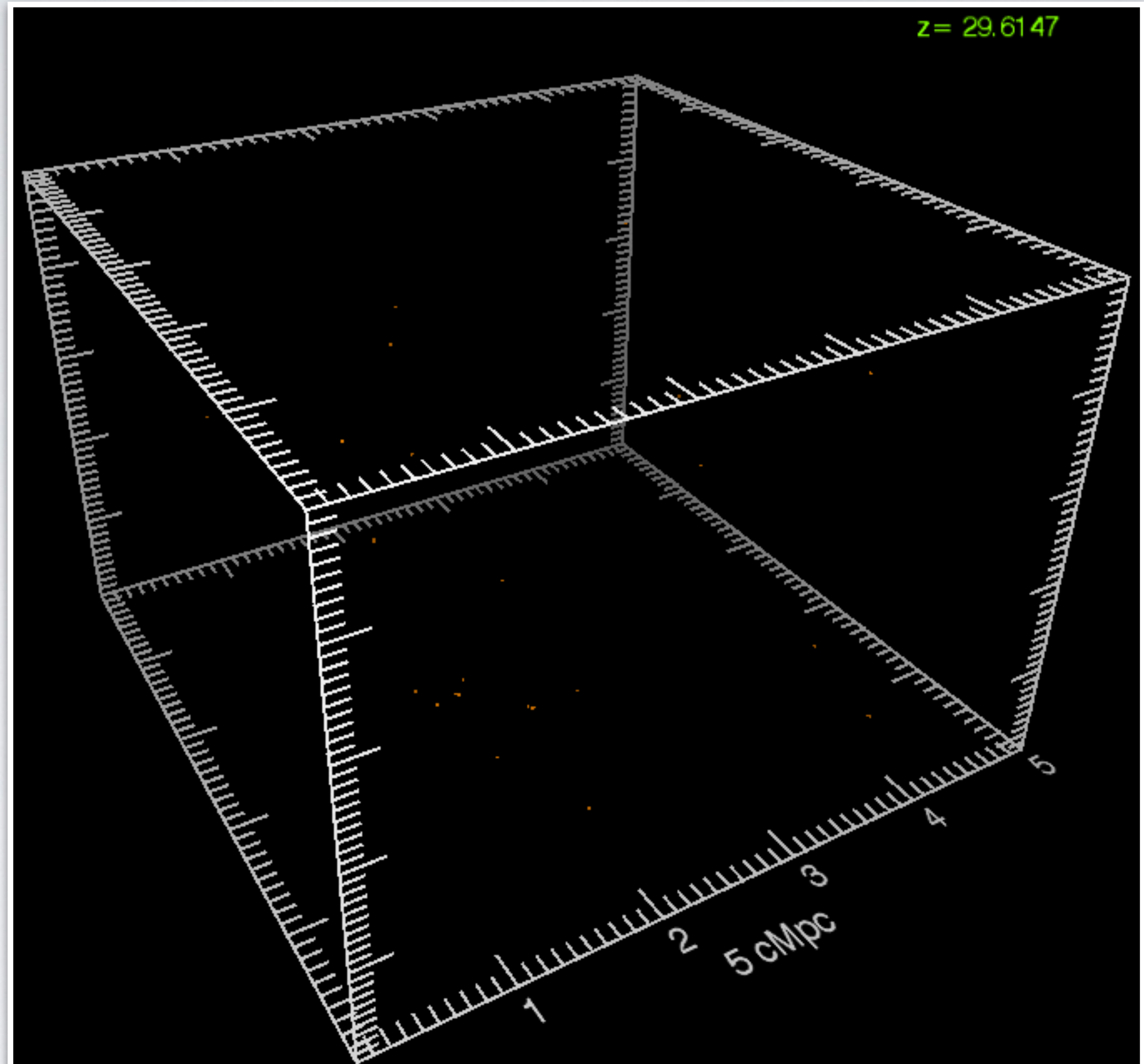


THEORETICAL MODELS: EXISTENCE

PART I & PART II

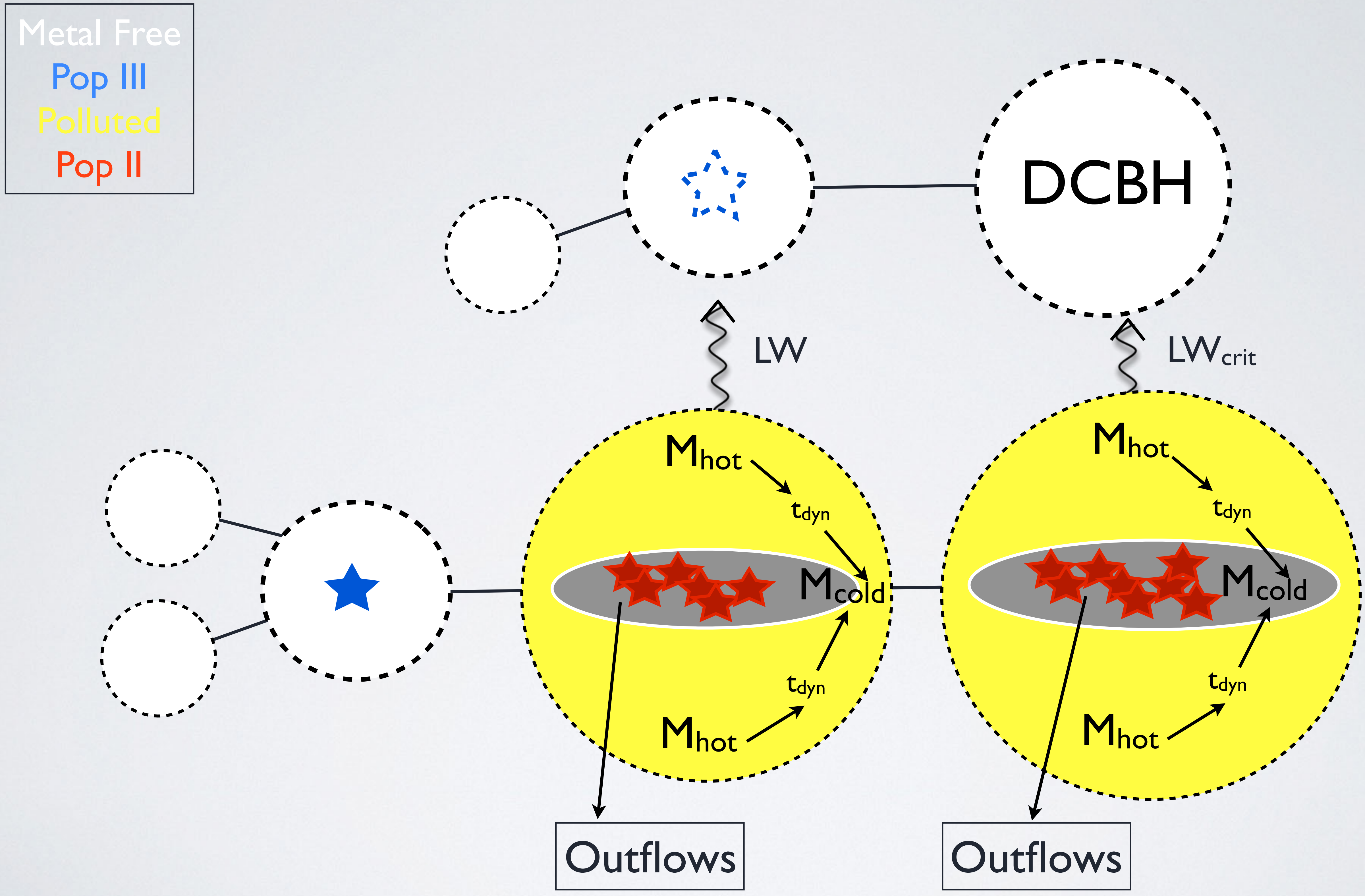
	SAM Agarwal et al. 2012	**FiBY** Dalla Vecchia et al.
Cosmological Volume	Yes	Yes
Minihaloes resolved	Yes	Yes
Halo histories	Yes	Yes
Outflows	Yes	Yes
Pop III + Pop II	Yes	Yes
LW radiation: Spatial + Global	Yes	Yes
Gas	**No**	Yes
IGM Metal Dispersion	**No**	Yes

SEMI ANALYTICAL MODEL



HOW THE MODEL WORKS

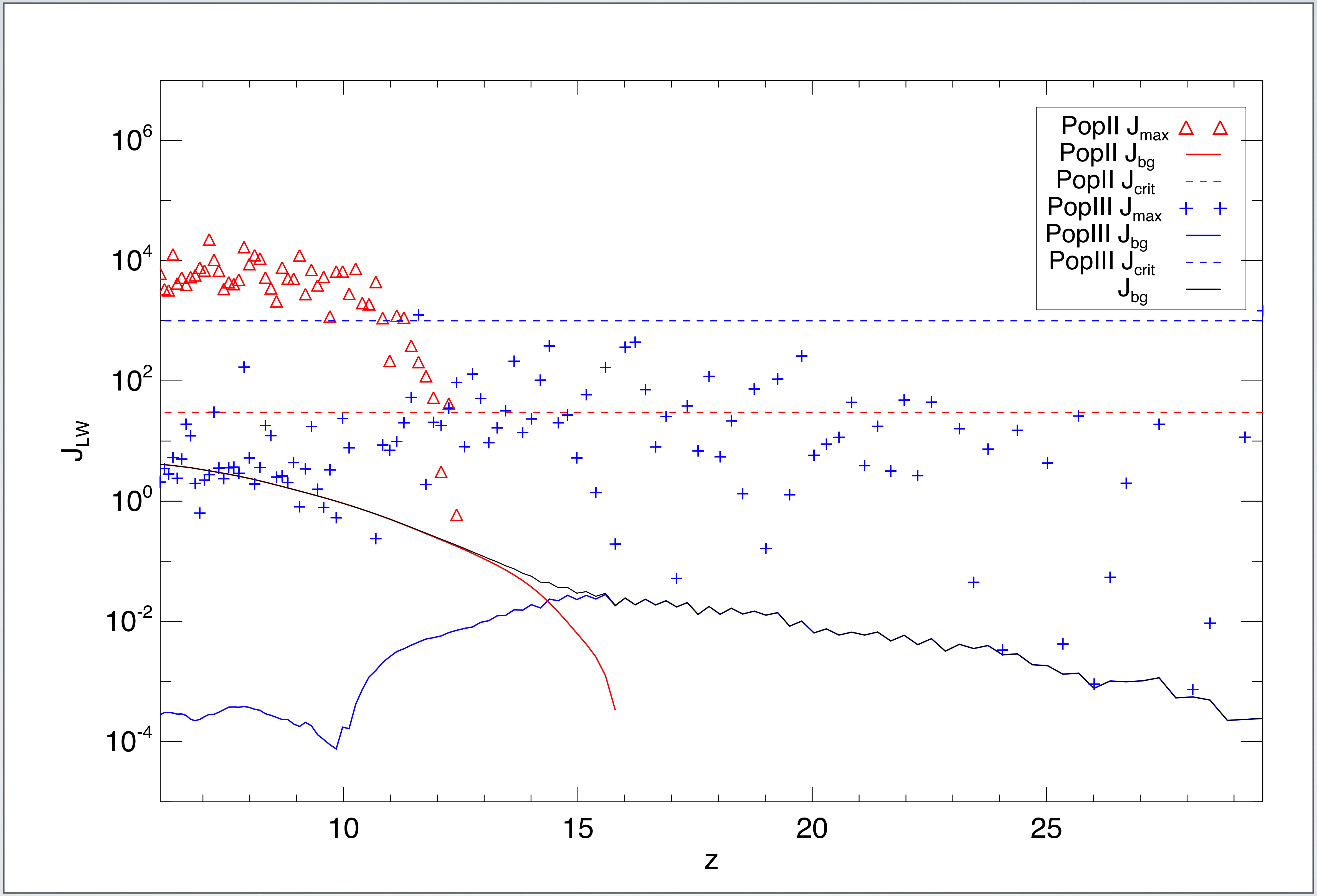
PART I: SAM



DC SITES

- How many such sites exist at z>6
- What is so special about *these* sites?
- What about their past, history of the halo/galaxy?
- How many such sites make a DCBH?
- How do they evolve?

HOW MANY DC SITES?



Agarwal et al. 2012

HOW MANY DC SITES?

DC sites: Few (<10) at z>6

in a

Qu

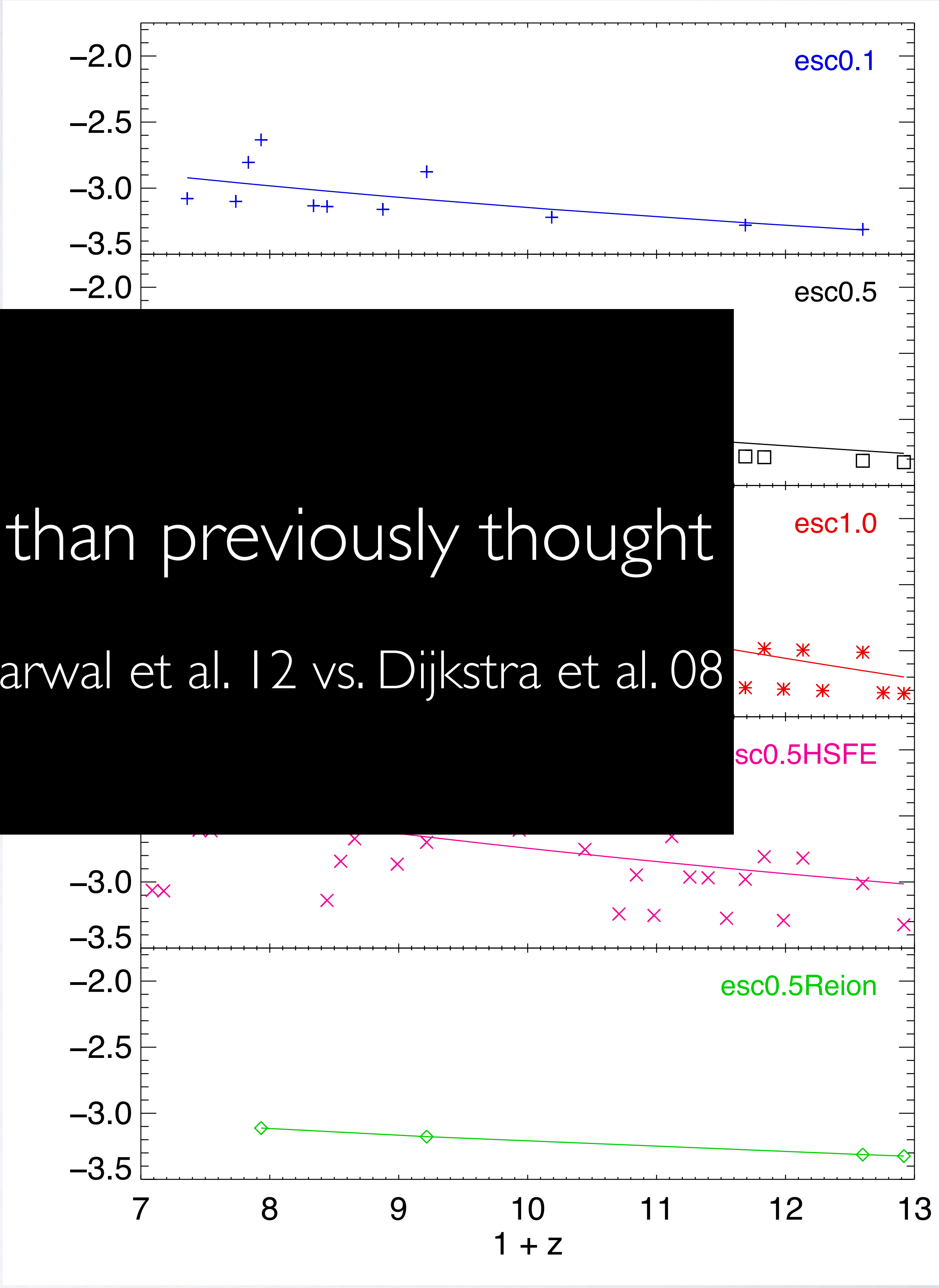
few

DC seems to be more probable than previously thought

Agarwal et al. 12 vs. Dijkstra et al. 08

Discrepancy:

10^7 objects too many! (?)



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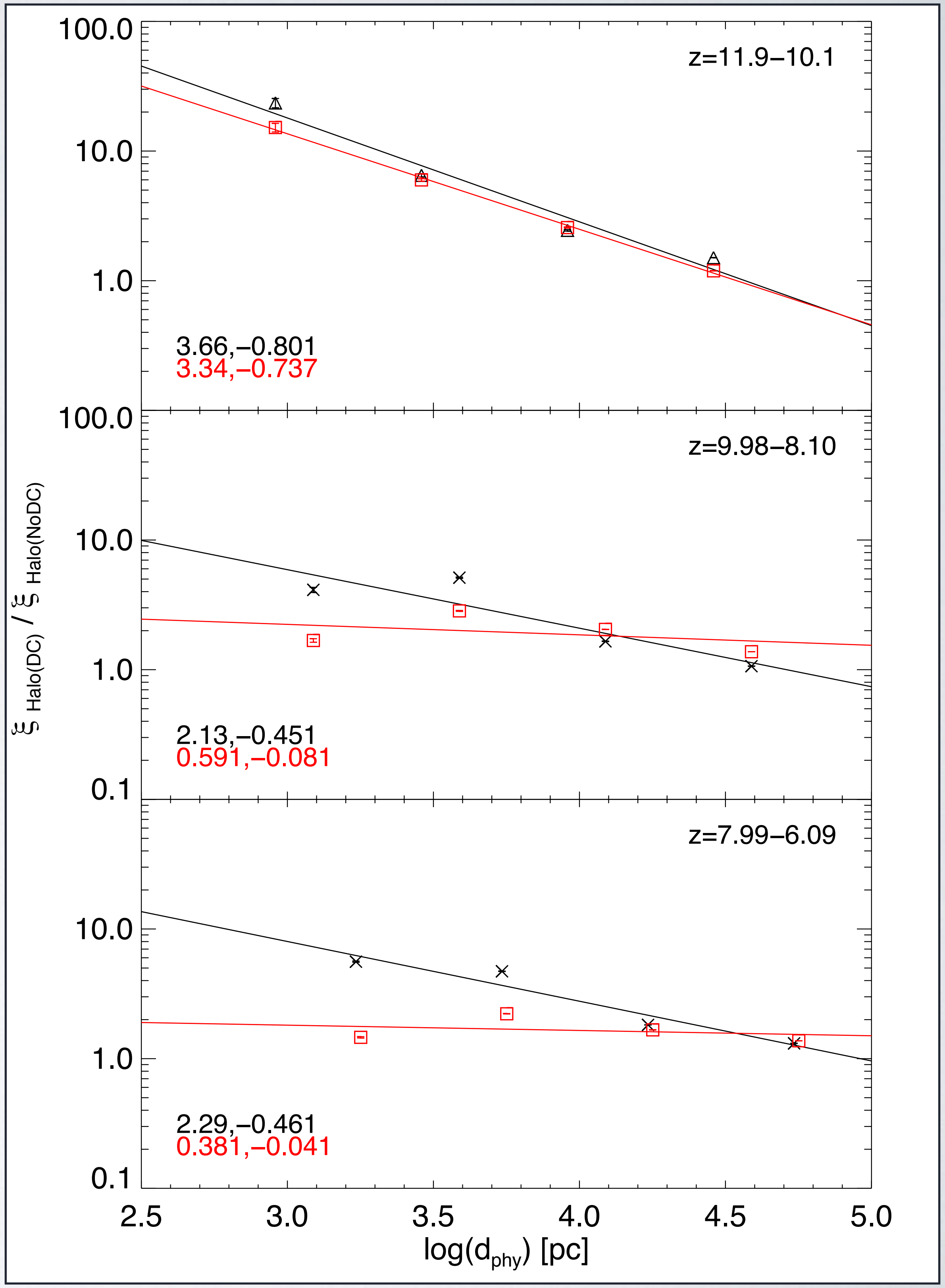
DC SITES: WHAT IS SO SPECIAL?

- Steeper Two point correlation

- DC sites prefer a more *clustered* neighbourhood

- Need to be *close* to a larger galaxy giving out critical LW flux



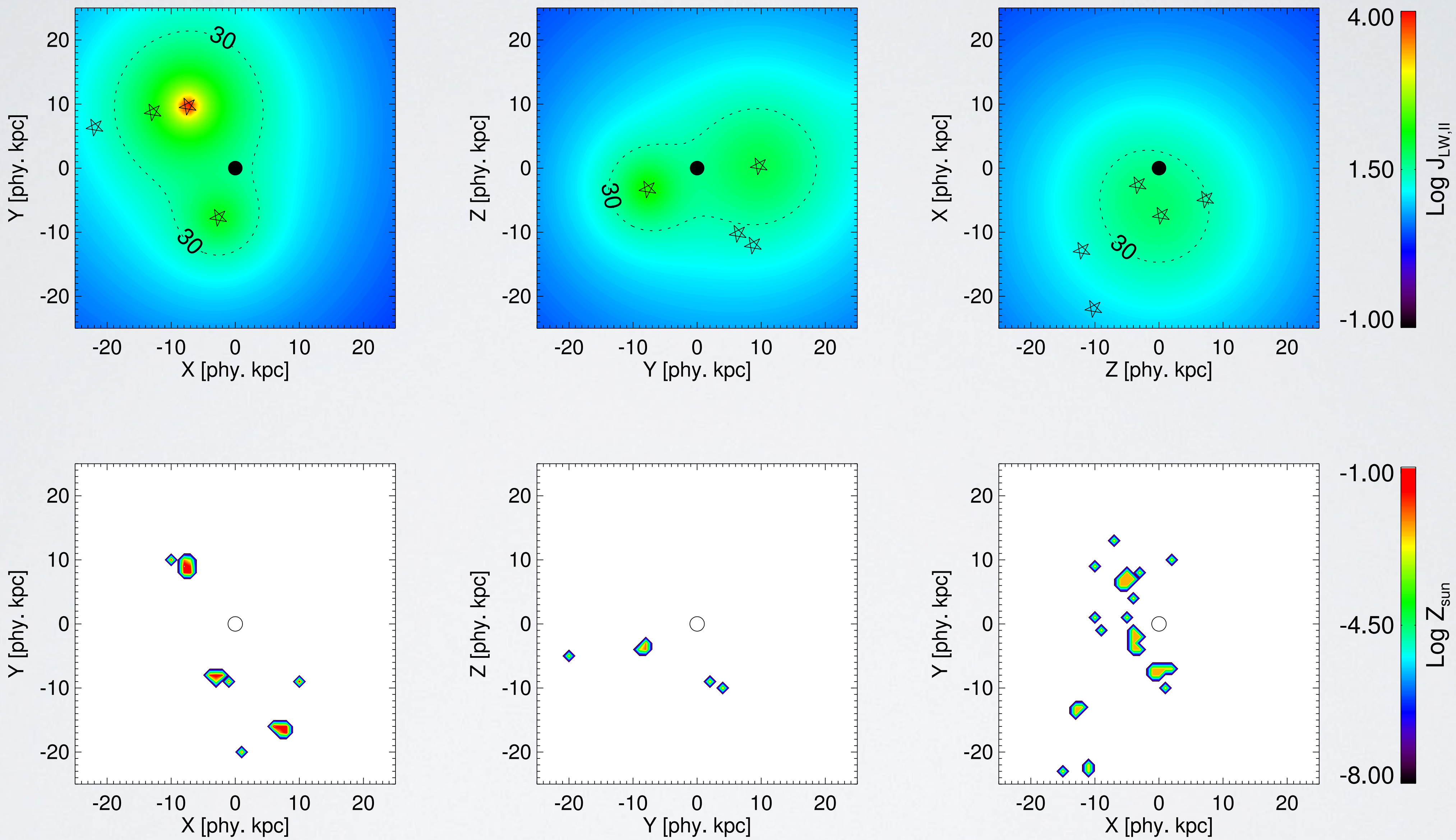
Agarwal et al. 2012

FIBY SIMULATION

COURTESY: CLAUDIO DALLA VECCHIA

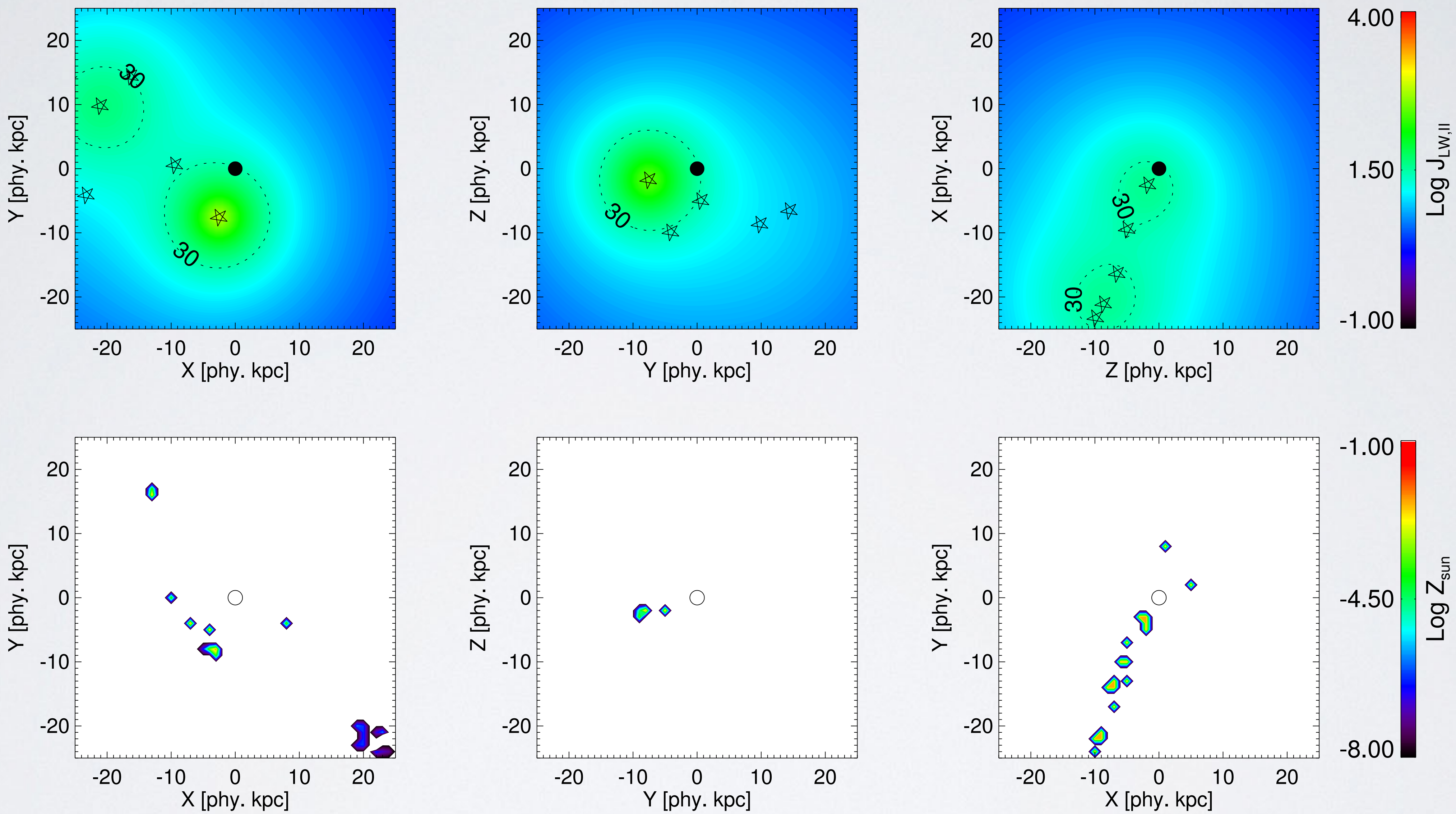
DC SITES: WHAT IS SO SPECIAL?

PART II: FIBY



Agarwal et al. 2014

DC SITES: WHAT IS SO SPECIAL?



Agarwal et al. 2014

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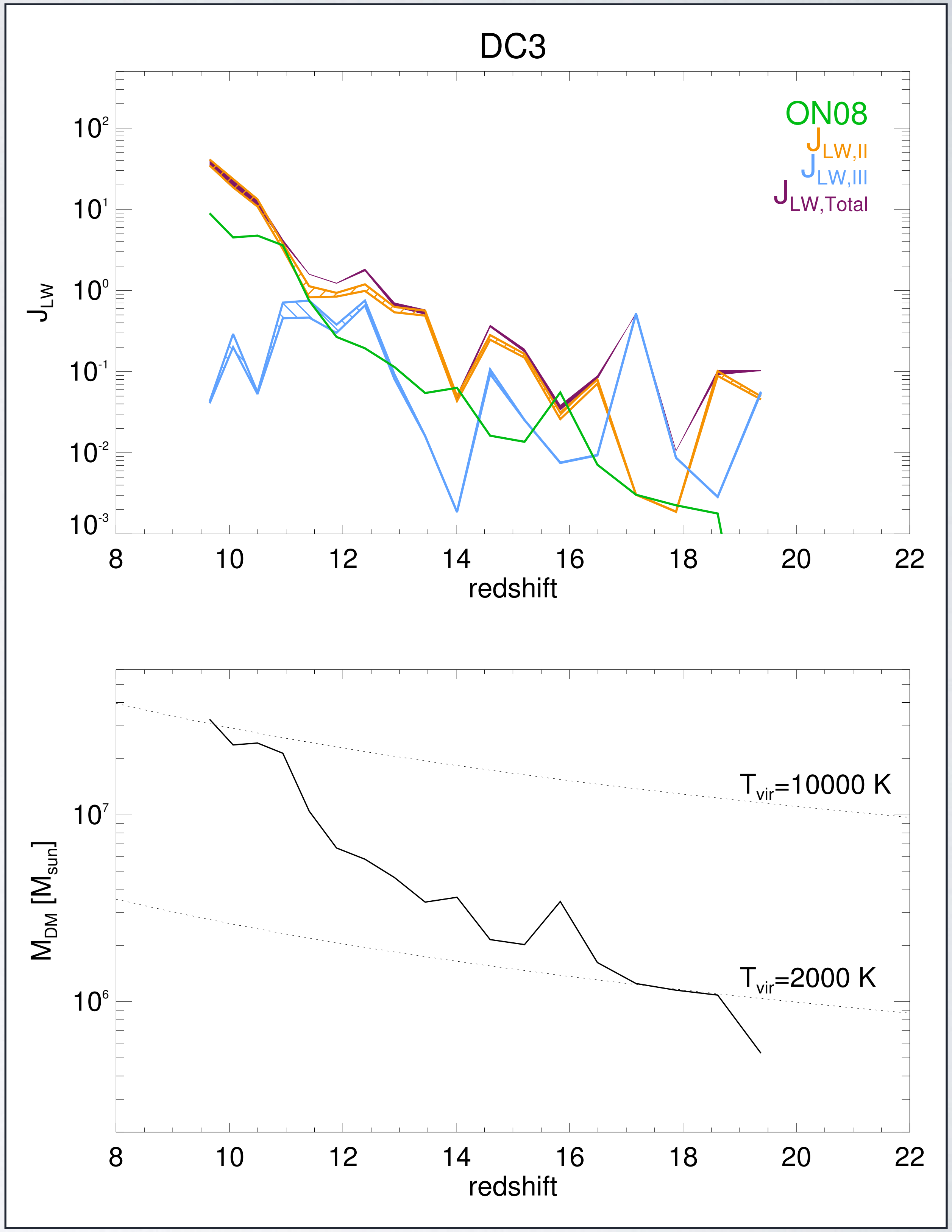
DC SITE: HISTORY

The DC site:

- avoids Pop III SF in its past

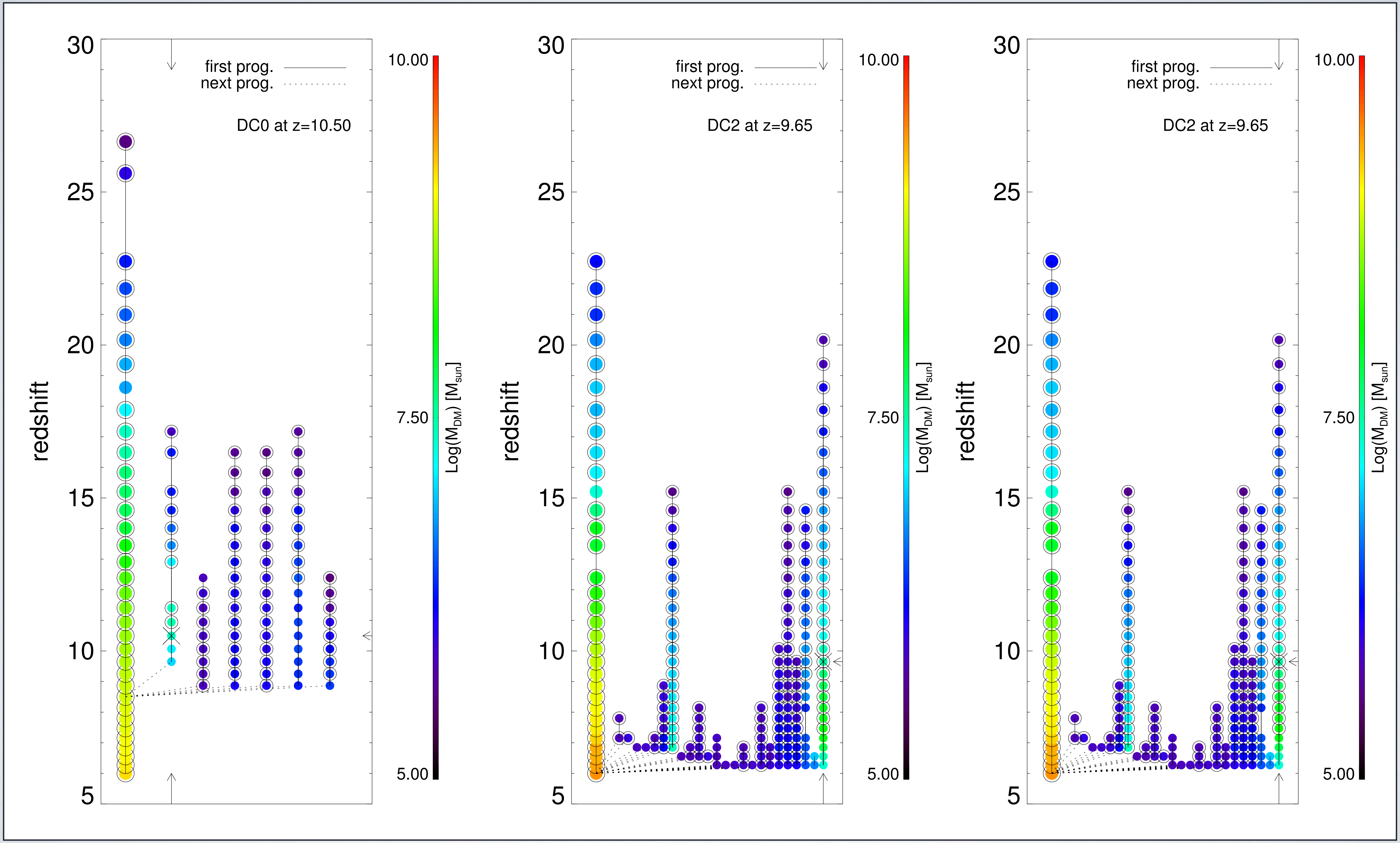
- remains unpolluted

- happens to be exposed to J_{crit} when it becomes atomic cooling



Agarwal et al. 2014

DC SITE: MERGER HISTORY



Agarwal et al. 2014

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Part I & II

Part III

MAKING A DCBH

- Atomic cooling halo, T > 8000 K
- Metal Free
- LW flux: critical value exceeded

— Avoid fragmentation and cooling to make Pop III stars

- Supermassive Star: turbulence vs. low angular momentum

Latif et al. 2013, Wise et al. 2008

- Nested instabilities: bars within bars to shed angular momentum

Volonteri et al. 2010

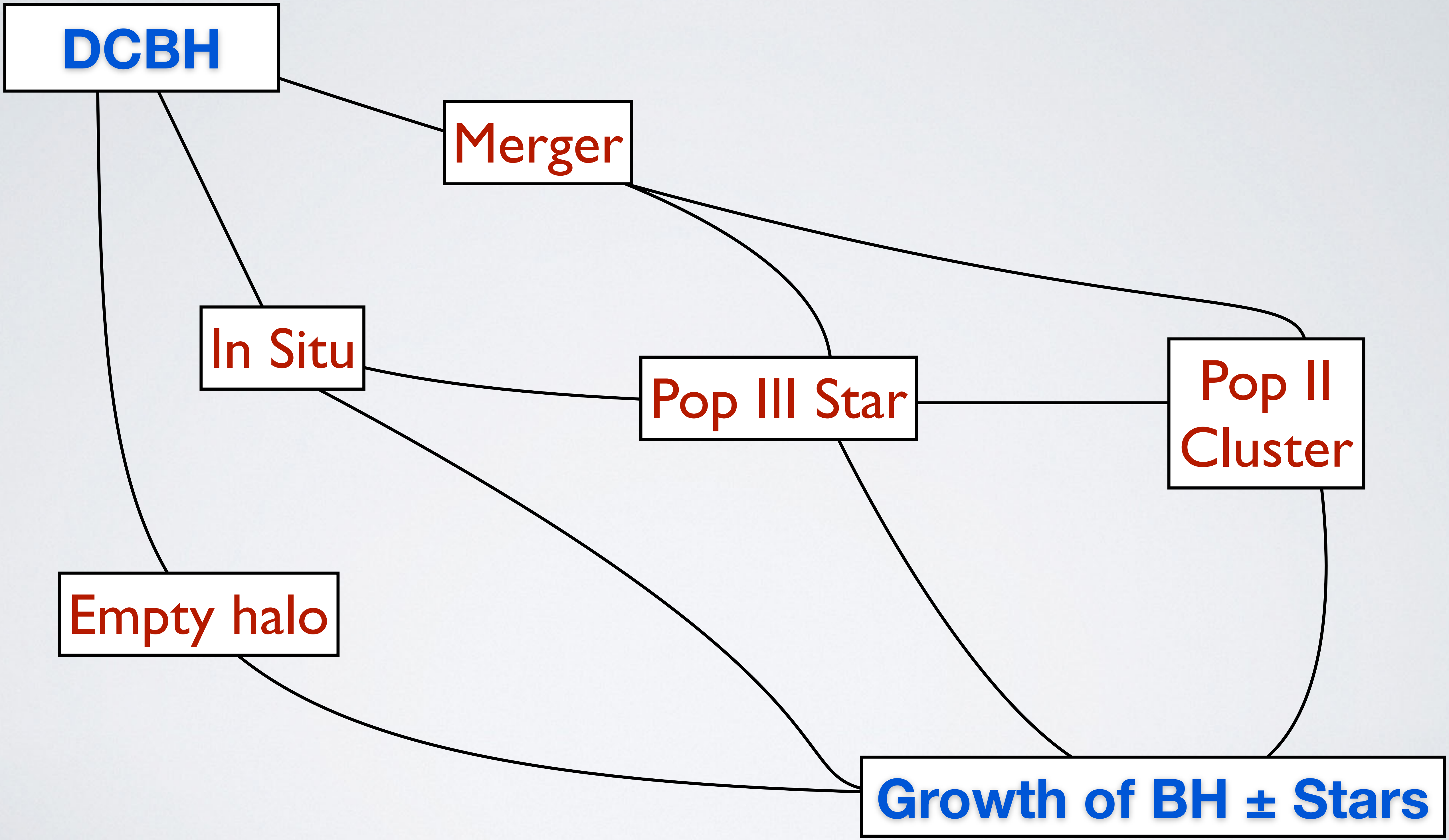
- Low spin disc: to relate the DM-halo spin to gas' angular momentum

Agarwal et al. 2013

Lodato and Natarajan 06/07

— **Strictly an upper limit**

GROWTH OF A DCBH



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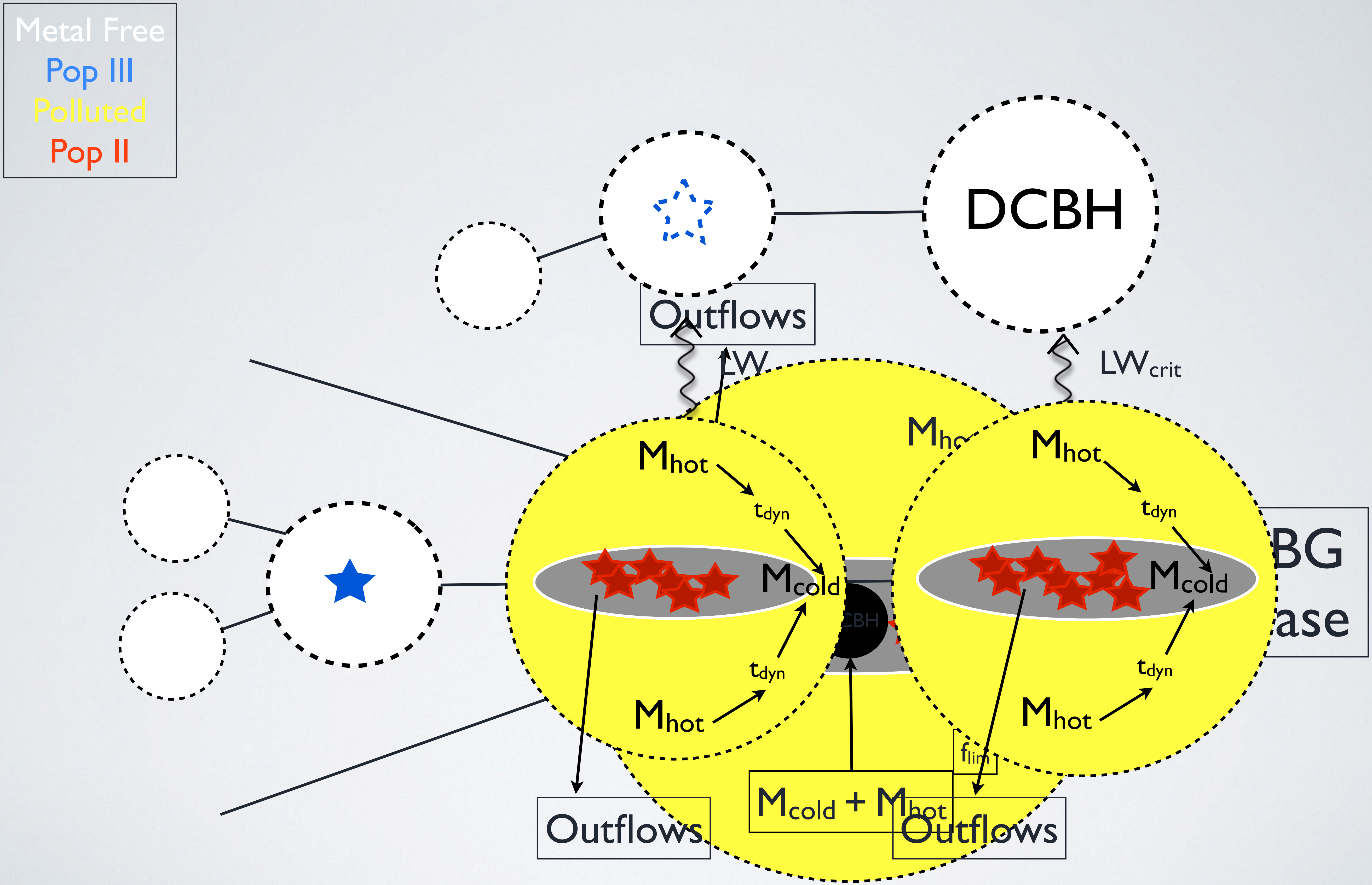
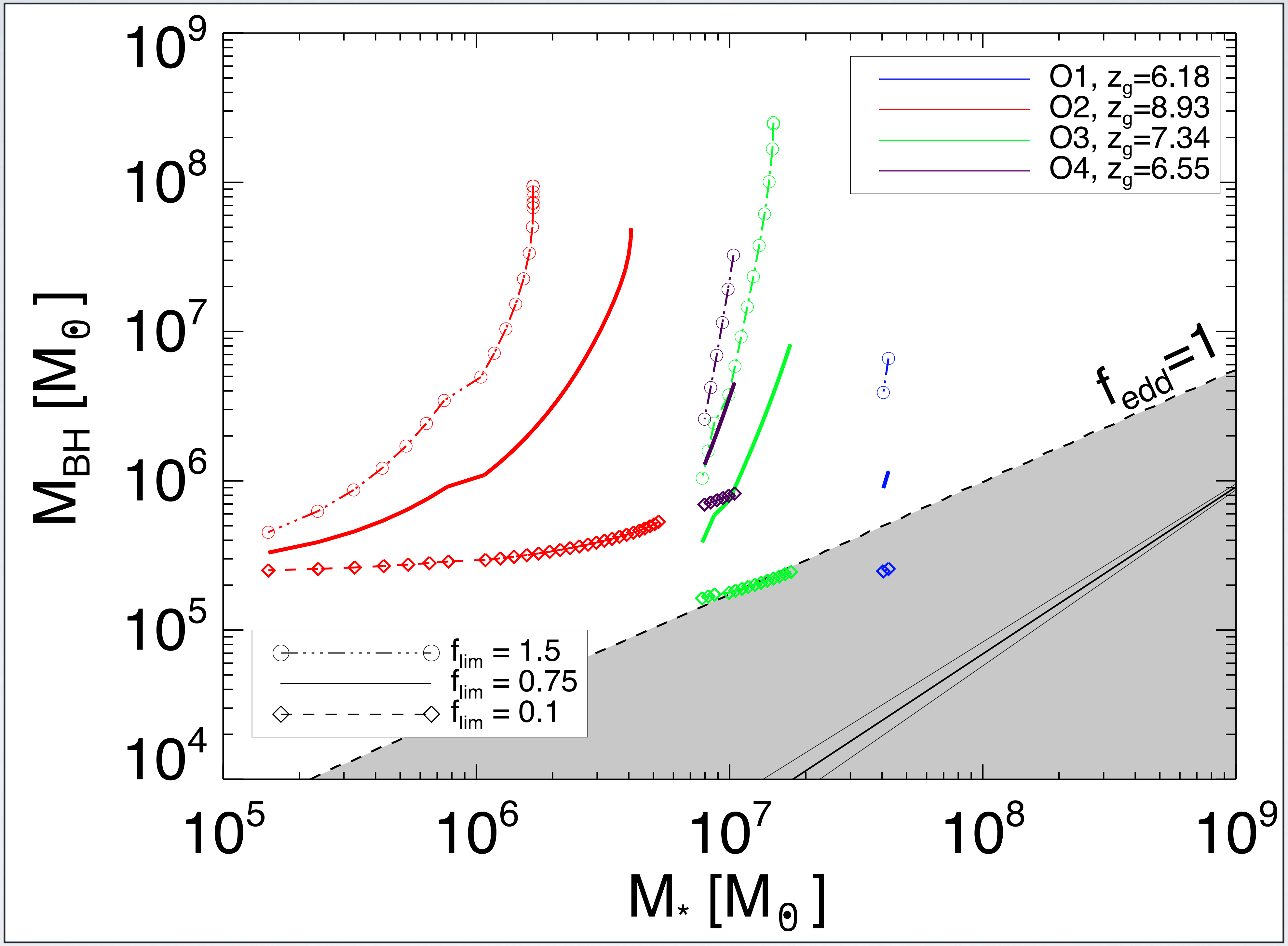


A NEW CLASS OF OBJECTS?

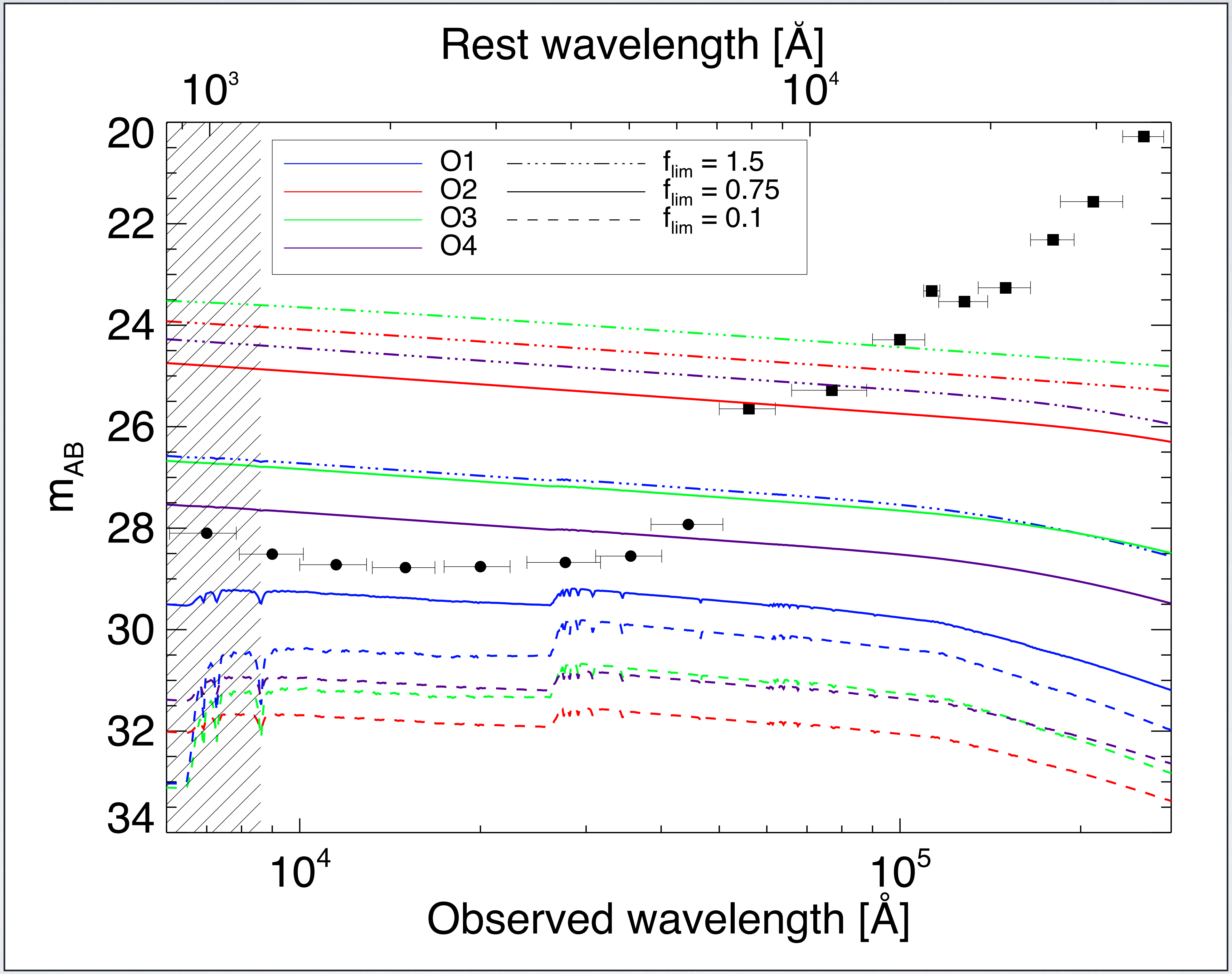
- Galaxies where a massive seed BH forms first
- Stellar component forms later
- BH ends up being obese and $L_{BH} > L_{star}$
- Obese Black Hole galaxies: OBG
- OBGs have distinct observational features

GROWTH OF DCBH: OBG



Agarwal et al. 2013

OBSERVING OBG



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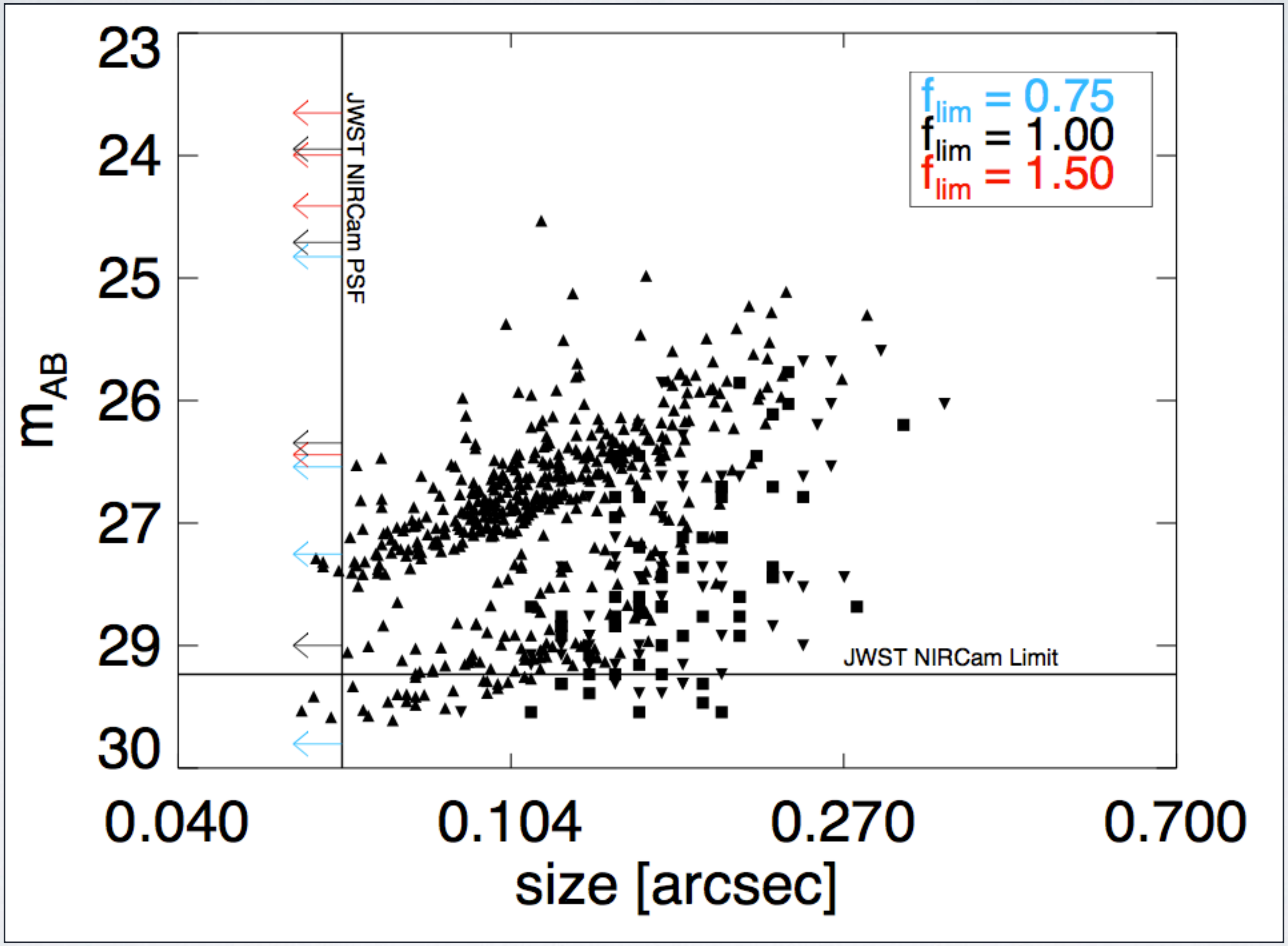

Agarwal et al. 2013

SUMMARY

- Possibility of DCBHs at z>6: higher than previously thought
- DCBHs form in satellites: mergers could lead to M_{BH} -M_{bulge}
- A new class of galaxies at z>6: obese black hole galaxies [OBG]
- Observational signatures at z < 6 (Rosario, Agarwal in prep)
- Revision in theories of DCBH formation (Agarwal et al. in prep)
- Impact *of* reionisation (Johnson, Whalen, Agarwal et al. in prep, Paardekoper, Agarwal et al. in prep)
- Impact *on* reionisation (Paardekooper, Agarwal et al. in prep)
- *Where do they end up : satellites or centrals?*

DC SITE: HISTORY