Local and Global Radiative Feedback in Pop III Star Formation

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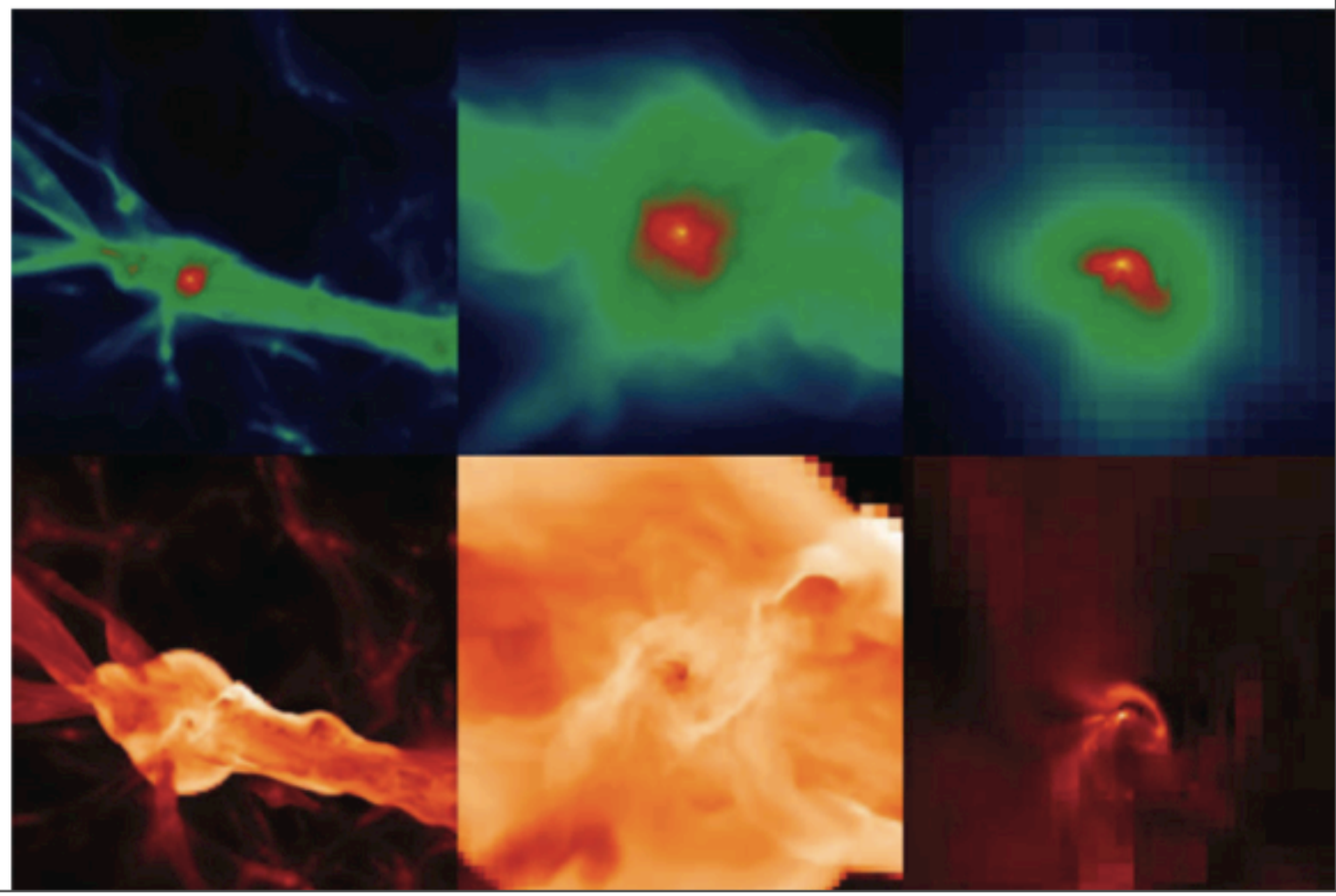


Conclusions

- It appears to be impossible to stop Population III stars from forming via the H_2 cooling mechanism - just to delay their formation
- Multifrequency rad hydro simulations of I-fronts interacting with halos suggest that these fronts can actually shield the halos from Lyman-Werner radiation in some circumstances
- We need to actually simulate high-σ peaks at high redshift (clusters of 'mini halos') and lower-σ peaks at all redshifts, with lots of physics, in order to get a true understanding of the Pop III star formation epoch

The Pop III.2 debacle

- "Pop III.2" is ambiguous, and perhaps implies greater coherency of thought than there really is
- Lyman-Werner radiation: photodissociation of H_2
- Ionizing radiation
  - Destroys H2; Ionizes H
  - Free electrons catalyze HD, H2 formation
- X-rays, cosmic rays, ...
- It's not clear whether all of this radiation is a net positive or negative

H_2-photodissociating radiation

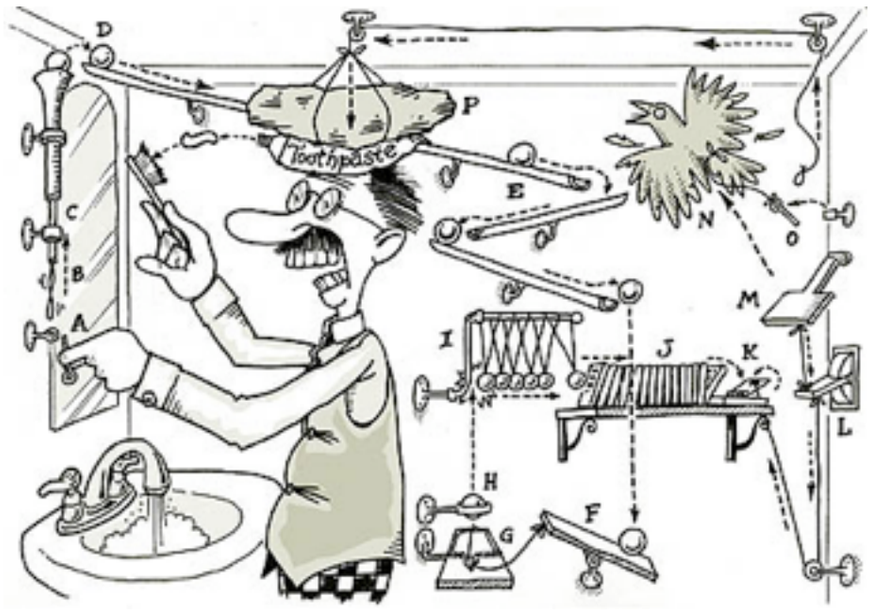
Effects of a soft UV background

- Photodissociation region around a Pop III star is much larger than the HII region
- Takes relatively few stars to build up a soft UV (Lyman-Werner) background which suppresses H_2 formation
- How does the destruction of H_2 affect properties of primordial stars?

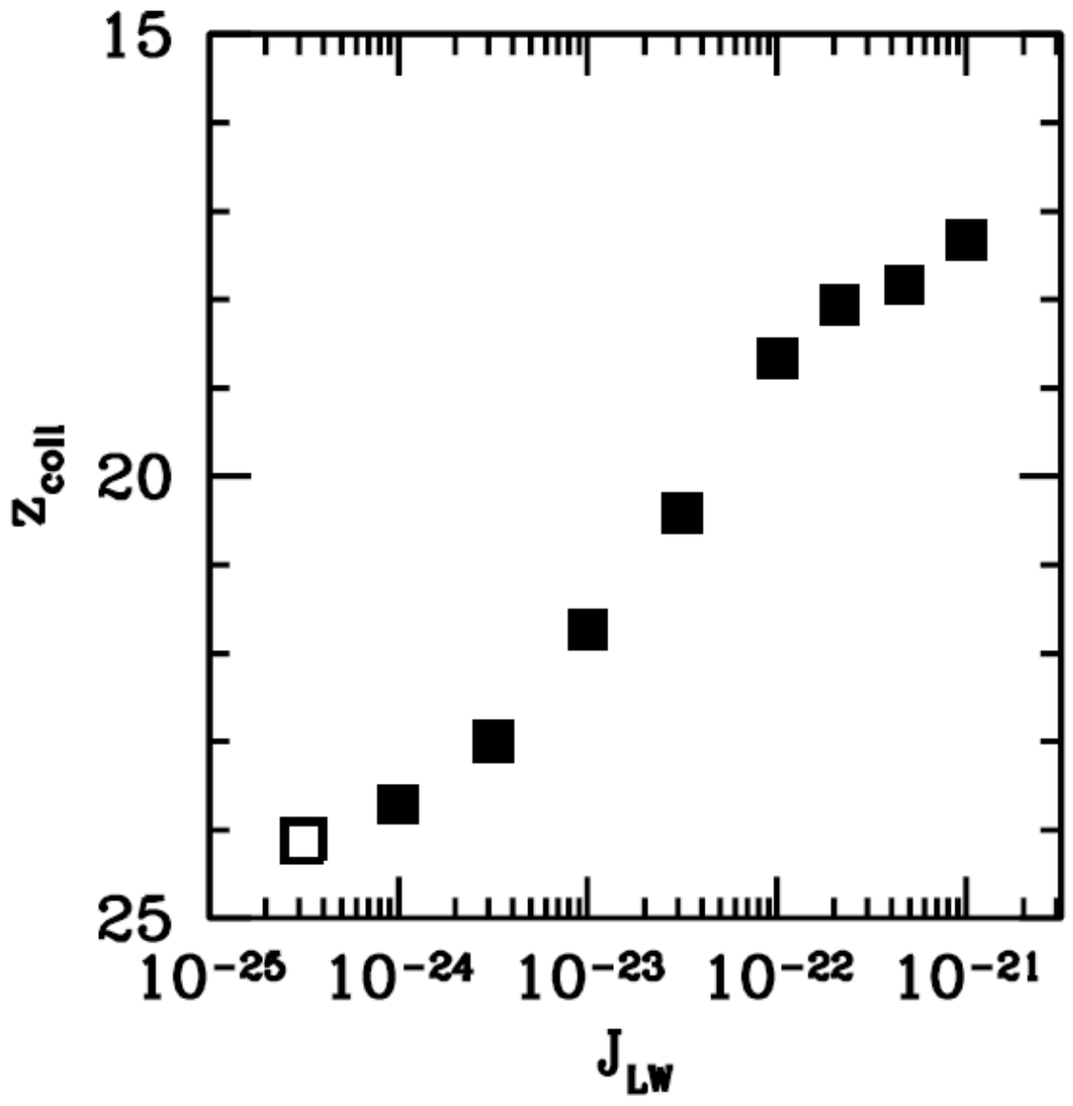
O'Shea & Norman 2008, ApJ, 673, 14

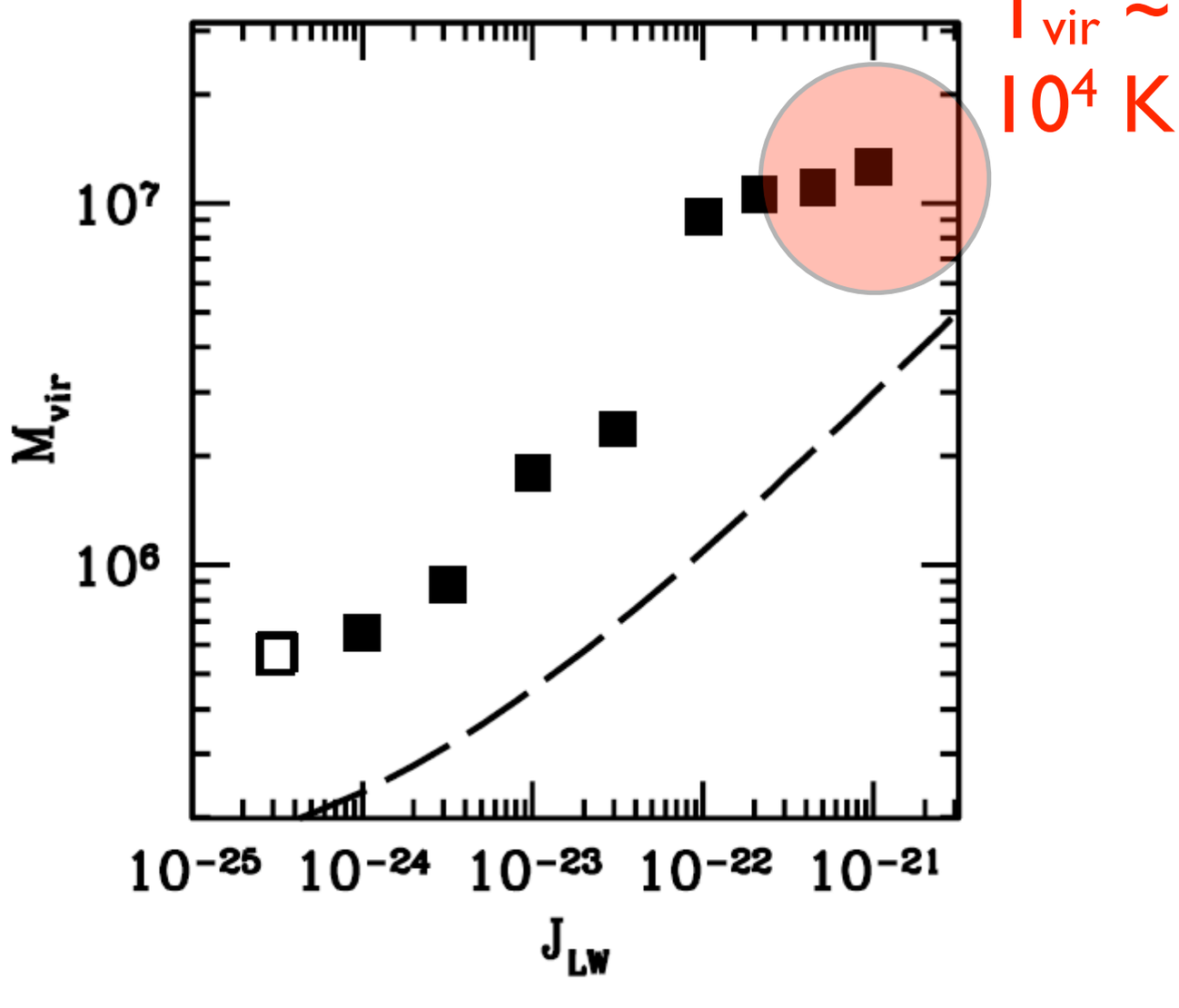
Numerical experiment

- Take one of our "standard" Pop III star formation simulations (ON 2007, ApJ, 673, 14)
- Start out with no photodissociating background; go up to largest reasonable value of J_{LW}, all using the same set of ICs
- Turn crank; see what happens!



Halo-scale effects of a soft UV background

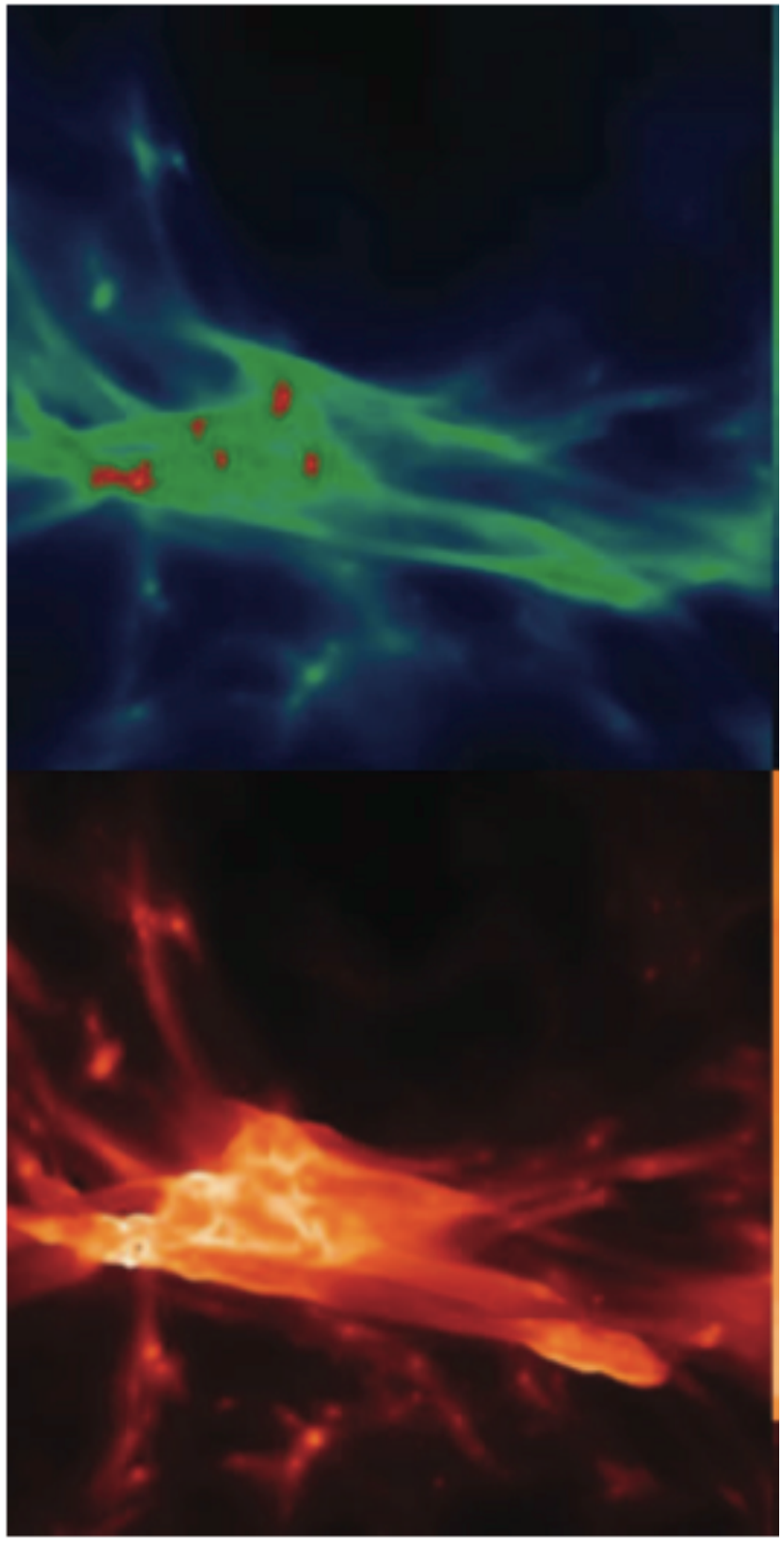


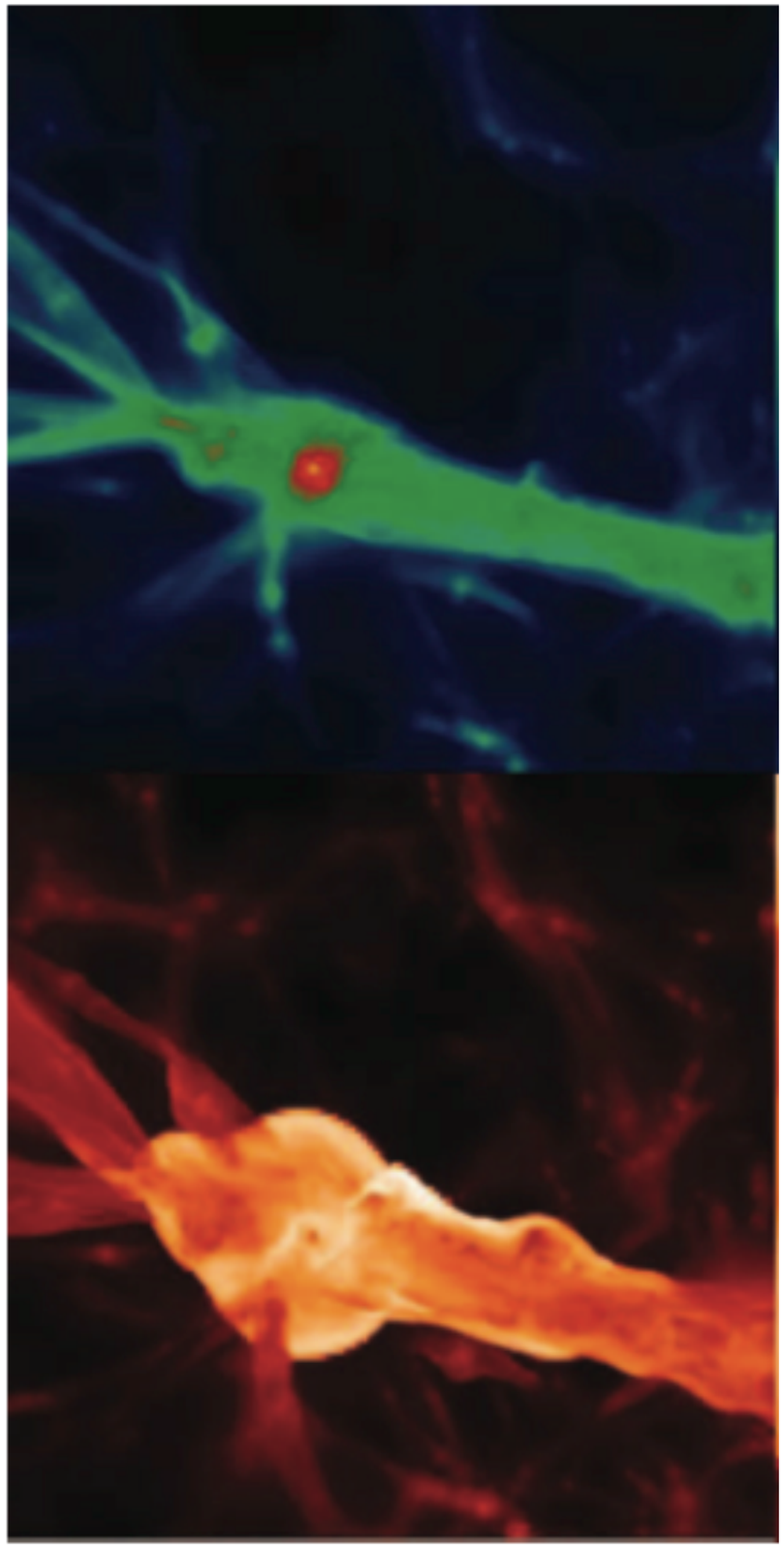


$T_{vir} \sim 10^4$ K

J_{LW} in units of ergs/s/cm^2/Hz/Sr

z_c = 24.1
M_v = 5.7e5



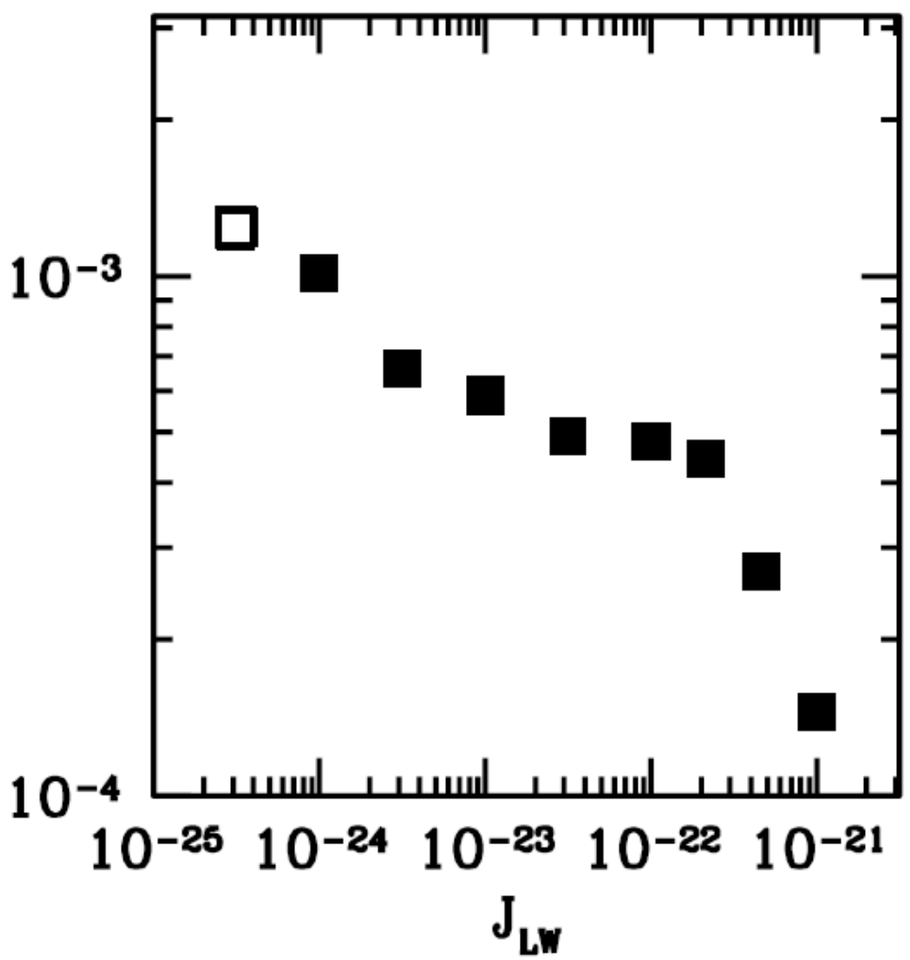


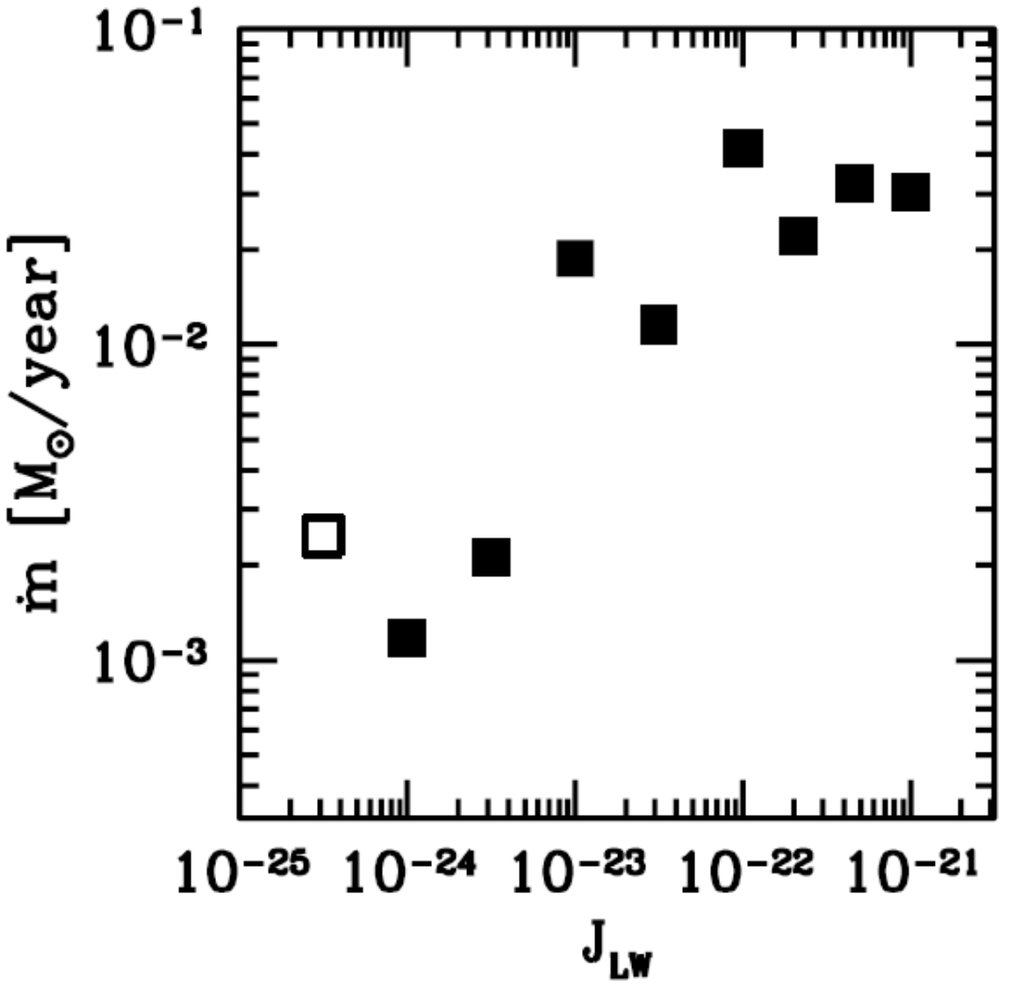
z_c = 17.3
M_v = 1.3e7

J_{21} = 0

J_{21} = 1

Effects of a soft UV background in halo core

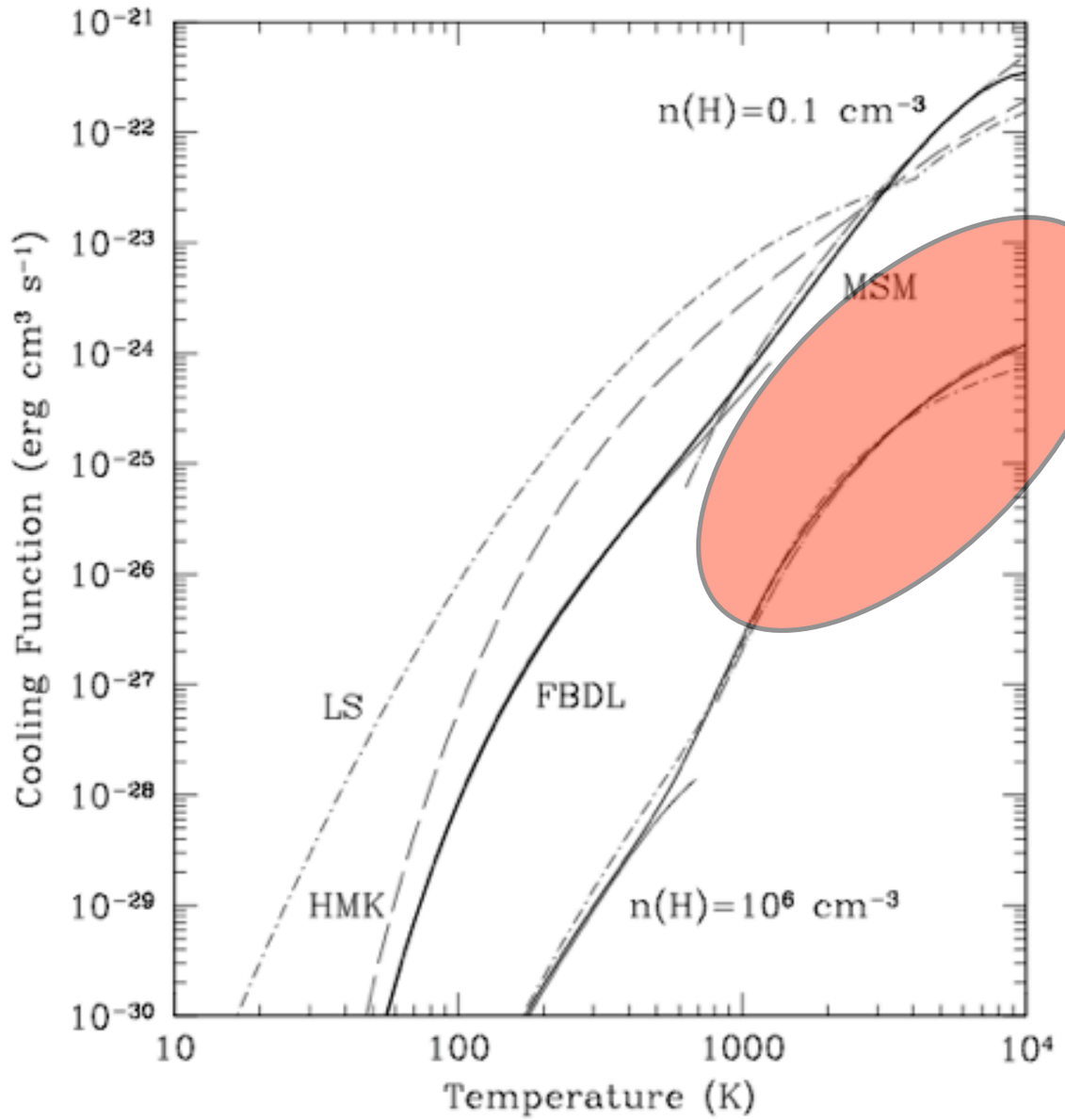




Why a LW background can't stop Pop III star formation

In a LW background:

$$f_{H_2} \sim \frac{k_H - n_e}{J_{LW}}$$



Galli & Palla 1998 A&A, 335, 403

Convergence of results (?)

- Machacek, Bryan & Abel 2001: FUV background imposes minimum halo mass, but does not completely quench star formation
- Wise & Abel 2007: even in very high FUV backgrounds, collisional ionization drives H2 formation faster than dissociation rates.
- FUV background only delays, and **never** suppresses, H_2 and thus Pop III star formation in $T_{vir} < 10^4$ K halos!

Ionizing radiation

HII regions from Pop III stars

- Pop III stars produce lots of high-energy photons, which destroy H2 and ionizing HI. (That's bad.)
- But, this creates lots of free electrons, which spurs H_2/HD formation. (That's good.)
- Cosmological simulations suggest that HII regions from Pop III stars may delay Pop III star formation in nearby halos, but ultimately make more H_2/HD than there would be otherwise. (That's ~~good~~ ~~bad~~ **?**)

Looking closer: rad hydro models of single halos

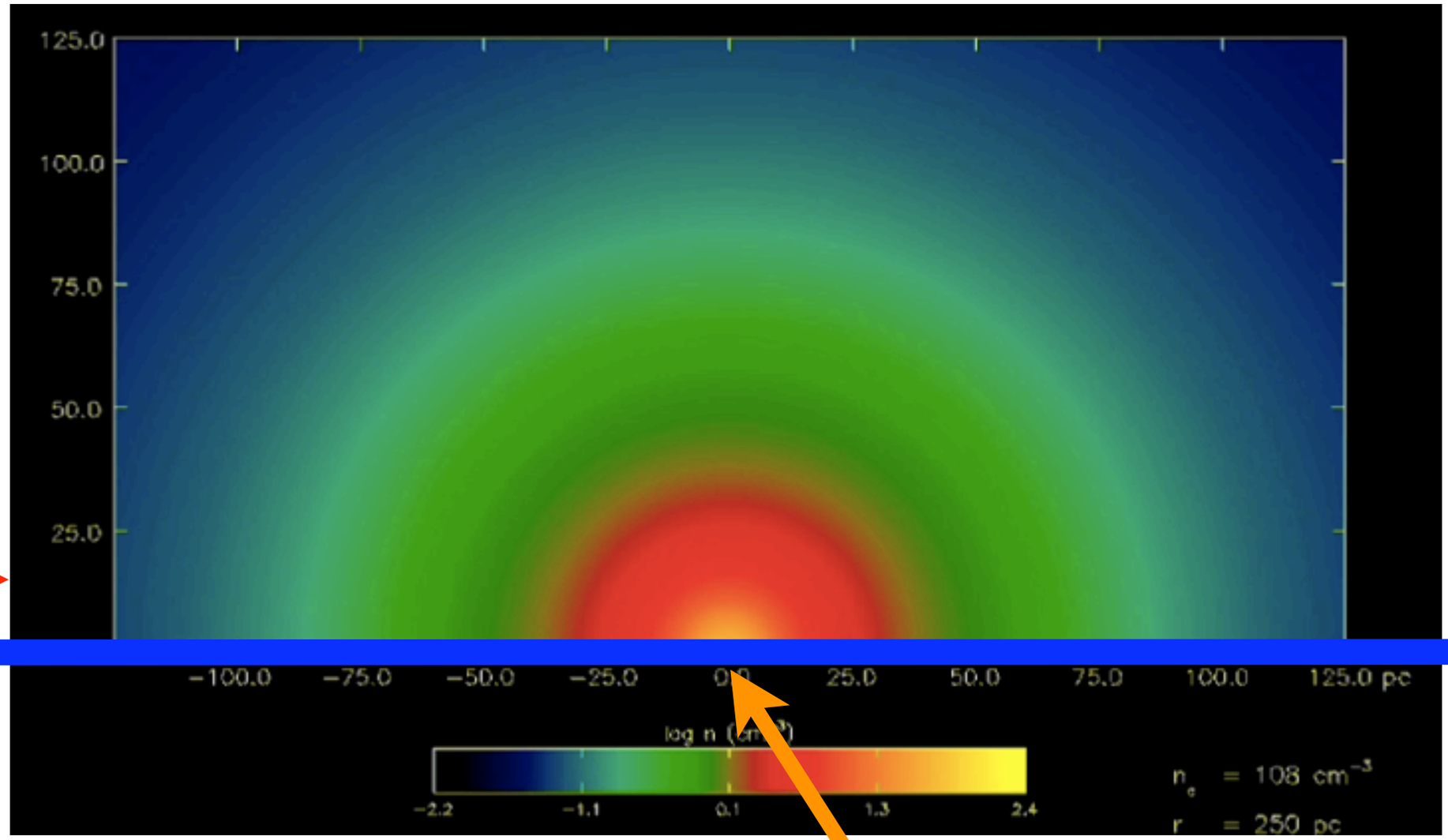
- Cosmological simulations approximate I-front interactions with gas in neighboring halos
- Multifrequency radiation transport, coupled to nonequilibrium primordial chemistry solver and hydrodynamics, can lead to very different results.
- I-fronts have finite widths, particularly for high-T stars! (like Pop III)

Whalen, O'Shea, Smidt & Norman 2008, ApJ, 682, 49
Whalen, Hueckstaedt & McConkie 2010, ApJ, 712, 101

Also see Hueckstaedt poster!

Example problem setup

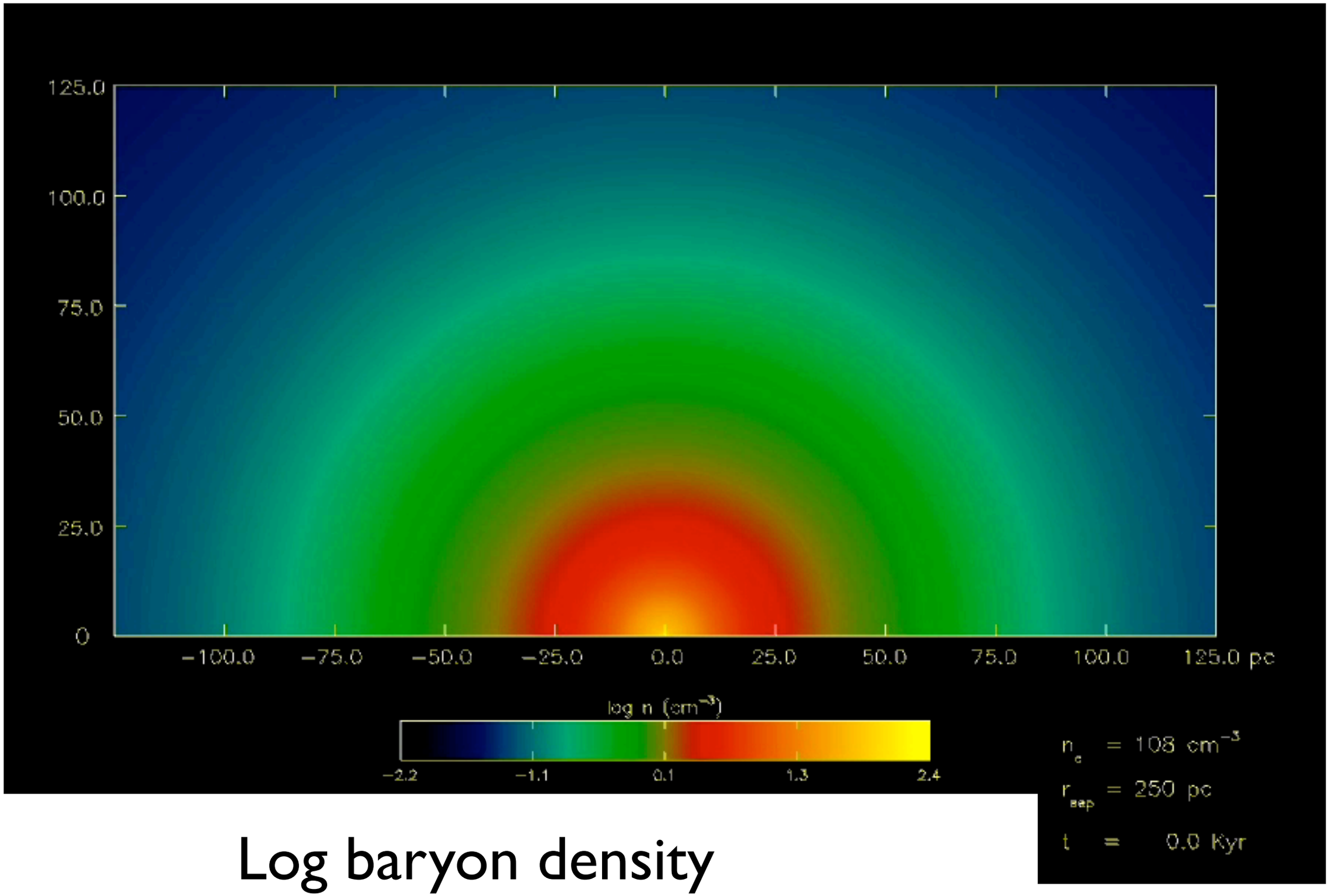
I-front
(10^5 K
Blackbody)



Axis of (cylindrical)
symmetry

Center of halo

25 $M_\odot$ Pop III star, 250 pc from halo halo

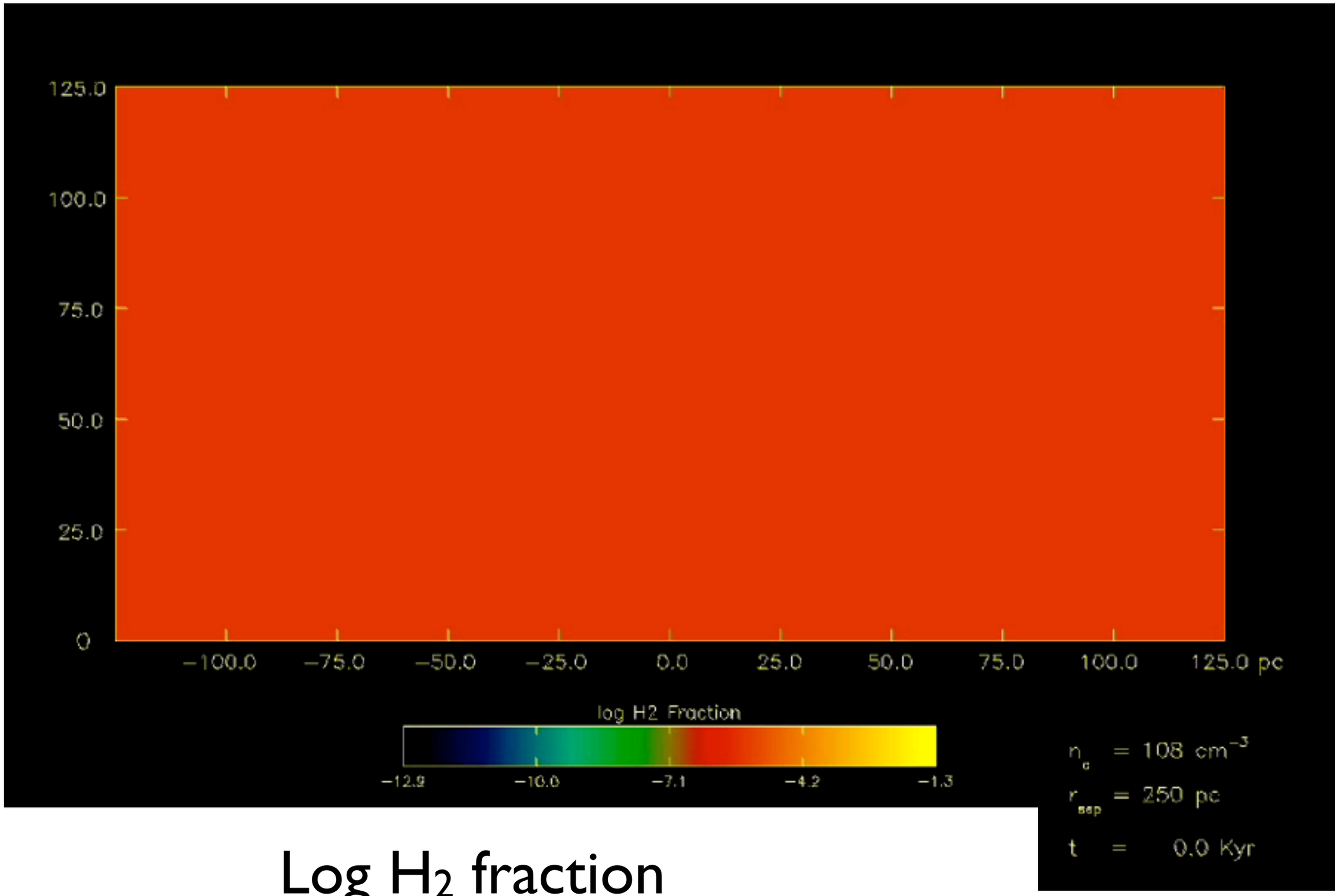


Log baryon density

Whalen, Hueckstaedt & McConkie 2010

(+ Hueckstaedt poster)

25 $M_\odot$ Pop III star, 250 pc from halo halo

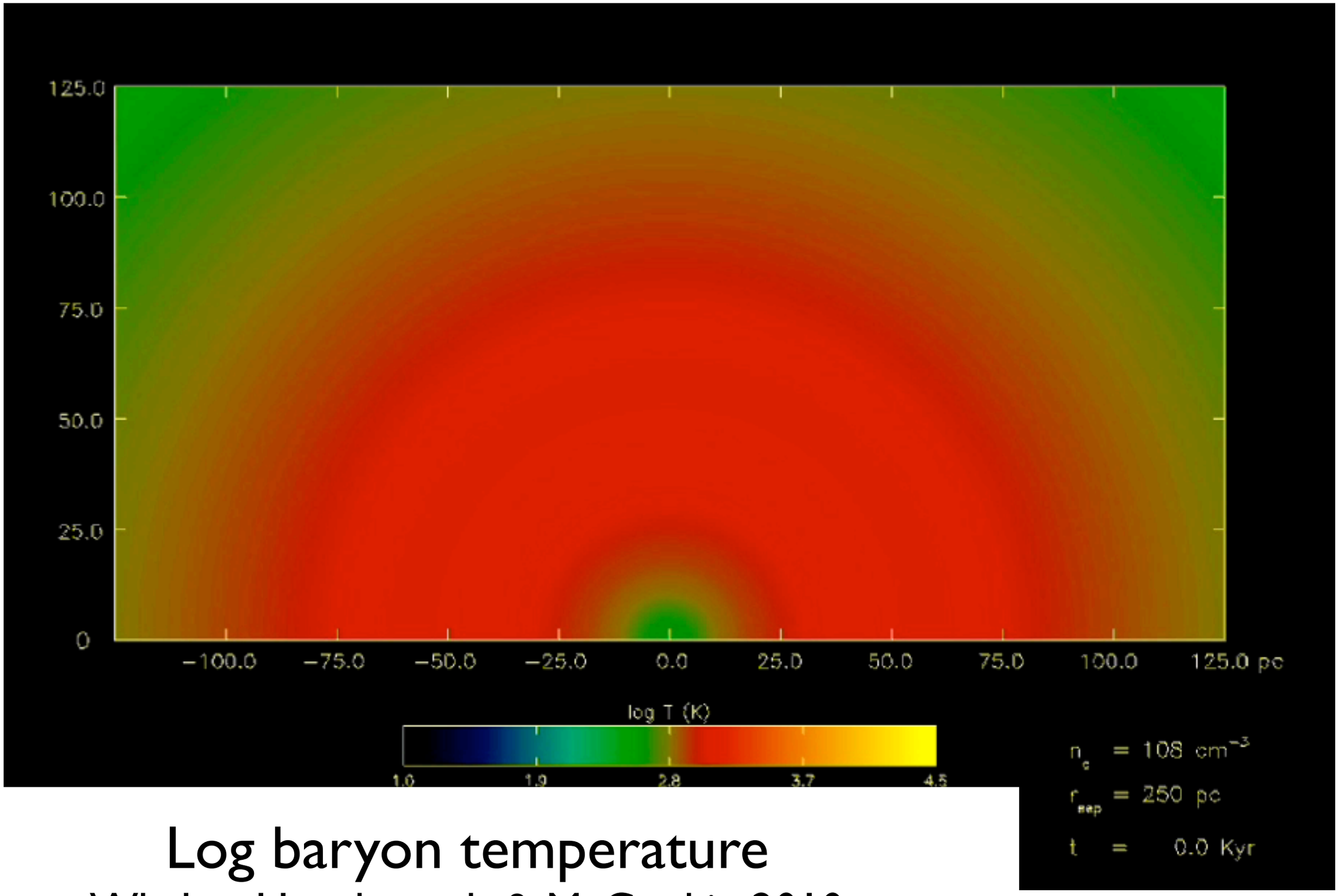


Log H_2 fraction

Whalen, Hueckstaedt & McConkie 2010

(+ Hueckstaedt poster)

25 $M_\odot$ Pop III star, 250 pc from halo halo



Log baryon temperature

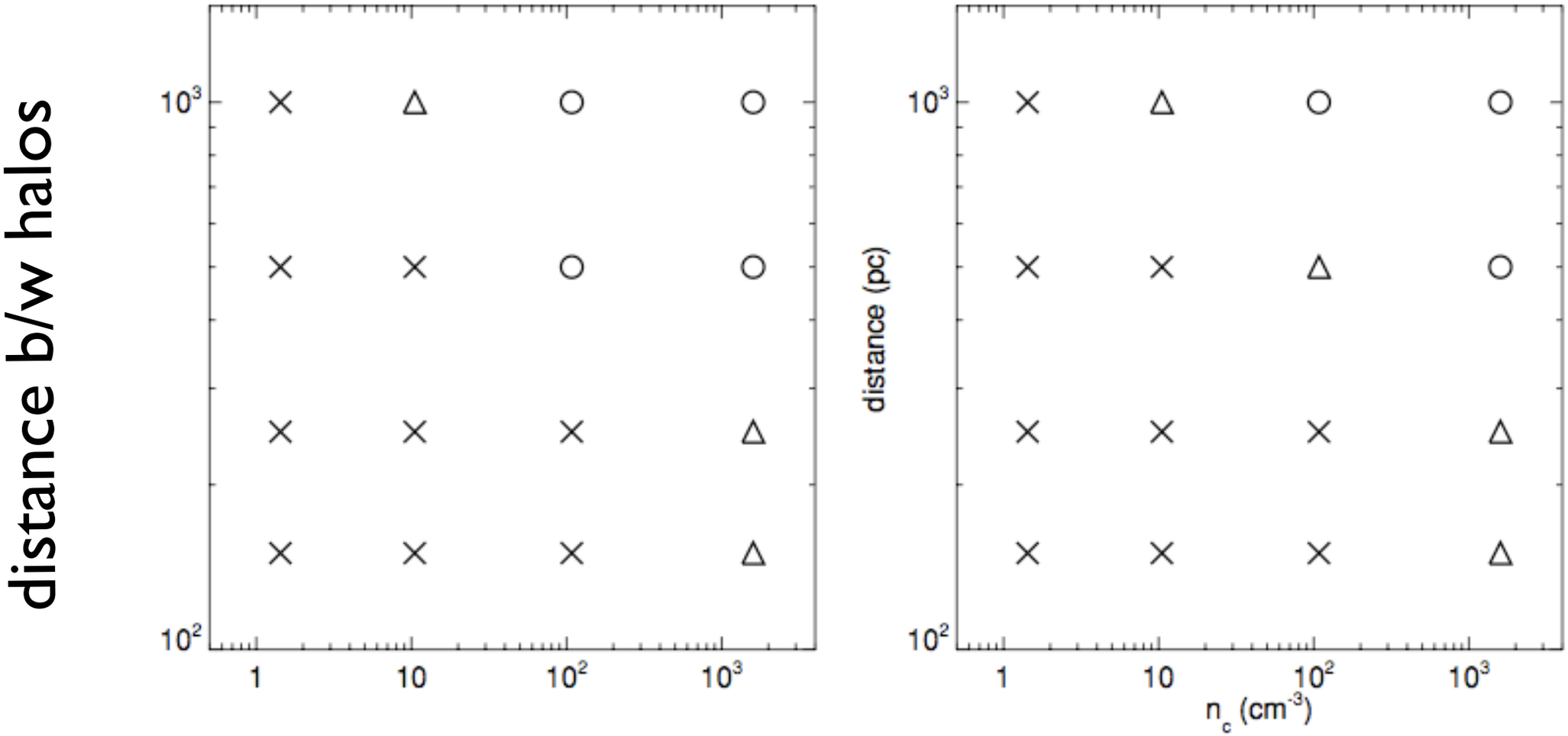
Whalen, Hueckstaedt & McConkie 2010

(+ Hueckstaedt poster)

The punchline (low-mass Pop III stars)

25 $M_\odot$ star

40 $M_\odot$ star

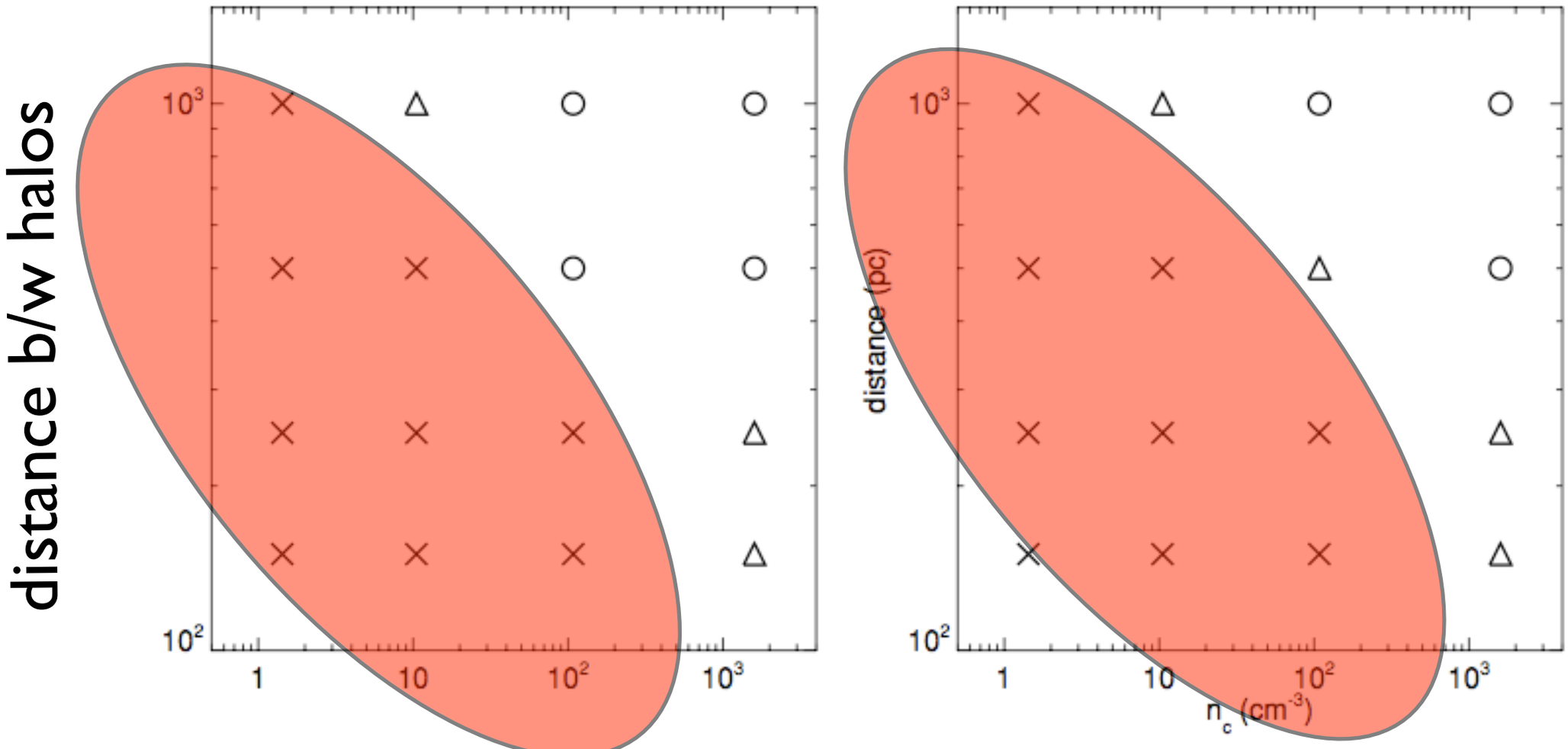


central baryon density

The punchline (low-mass Pop III stars)

25 $M_\odot$ star

40 $M_\odot$ star

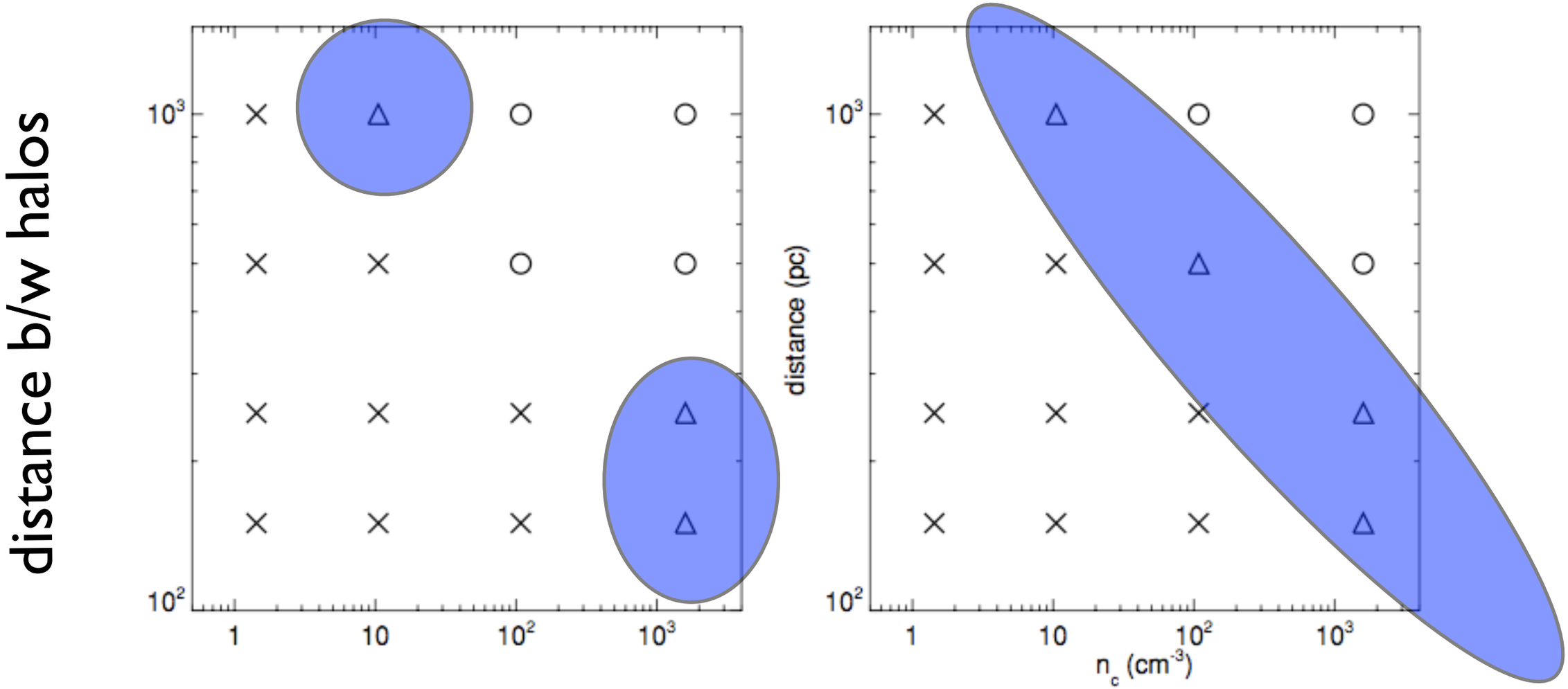


Halos completely evaporated

The punchline (low-mass Pop III stars)

25 $M_\odot$ star

40 $M_\odot$ star



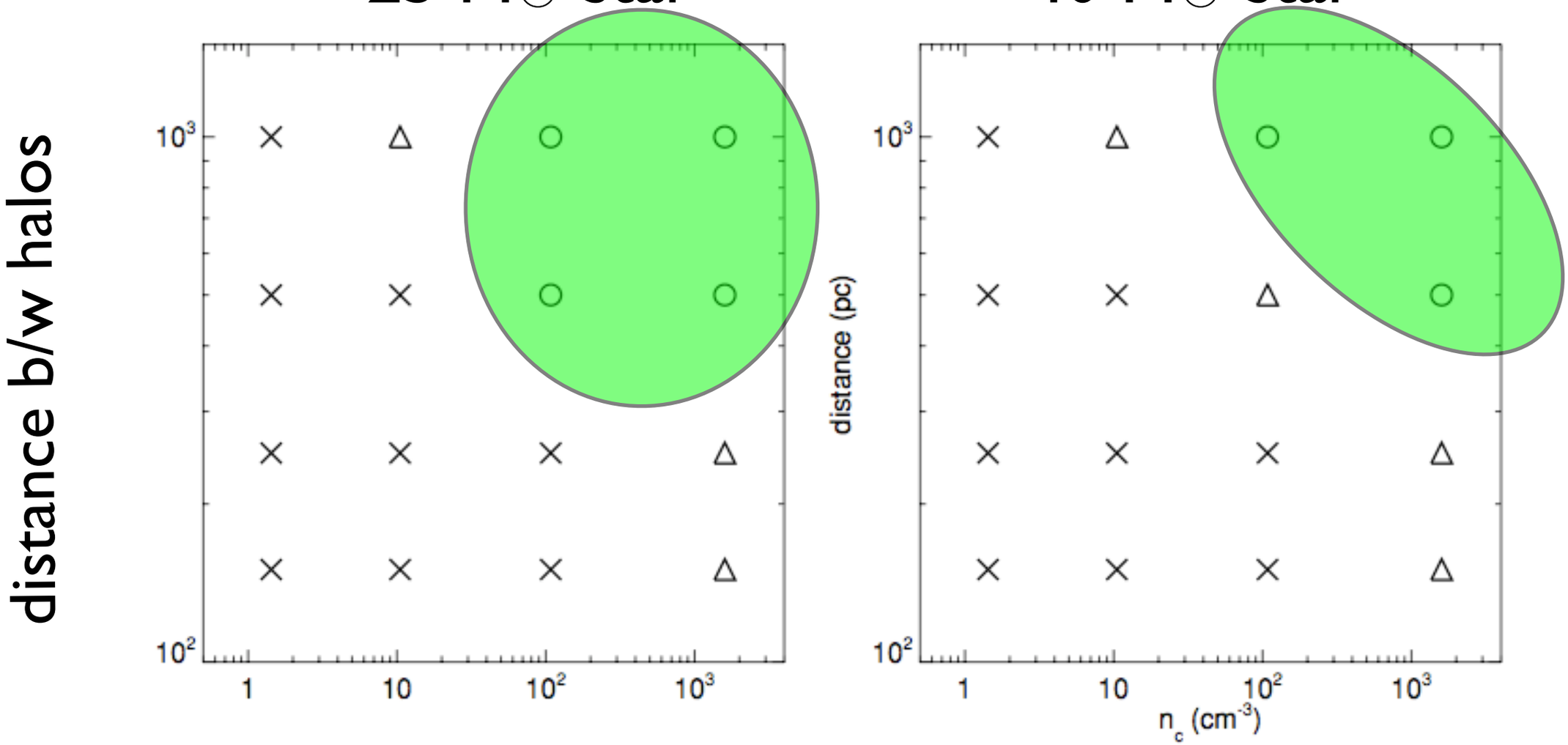
central baryon density

Delayed star formation

The punchline (low-mass Pop III stars)

25 $M_\odot$ star

40 $M_\odot$ star



central baryon density

Star formation completely unaffected

Ionizing radiation, more generally

- Bubbles of ionizing radiation 'percolate' at high z: some halos may stay ionized for a long time and not form H2 at all!
- At later times, universe is completely ionized - many primordial halos exist, but gas can't collapse within them
- At z ~ 6 and below: some primordial star formation in voids? (Trenti)

I still haven't talked about...

- X-rays (Machacek et al., Ricotti et al.) - heat up gas, produces free e-, probably promotes H_2 formation
- Cosmic rays (Stacy & Bromm) produced by Pop III supernovae can reach farther than metals from star - probably promotes H_2 formation.
- Binary Pop III stars (?)

Lots of competing effects!

Pop III stars strongly clustered = lots of cross-talk!

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