Dark matter and the first stars

Fabio Iocco

Marie Curie fellow at

Institut d'Astrophysique de Paris

In collaboration with:

A. Bressan, A. Ferrara, P. Marigo, E. Ripamonti, R. Schneider

First Stars and Galaxies, Austin, 3/8/10

Outline

- Self-annihilating DM and first stars: two mechanisms

- Gravitational contraction (until proto-star forms)
  → Feedback effects (no Jeans mass modification)
  → DM supported hydrostatic core, short phase
  → No Supermassive object formation observed

- Capture by scattering (active at ZAMS gas density + timescale arguments)
  → Lifetime prolongement (as long as conditions are favorable)

- Which effects on the Population III?

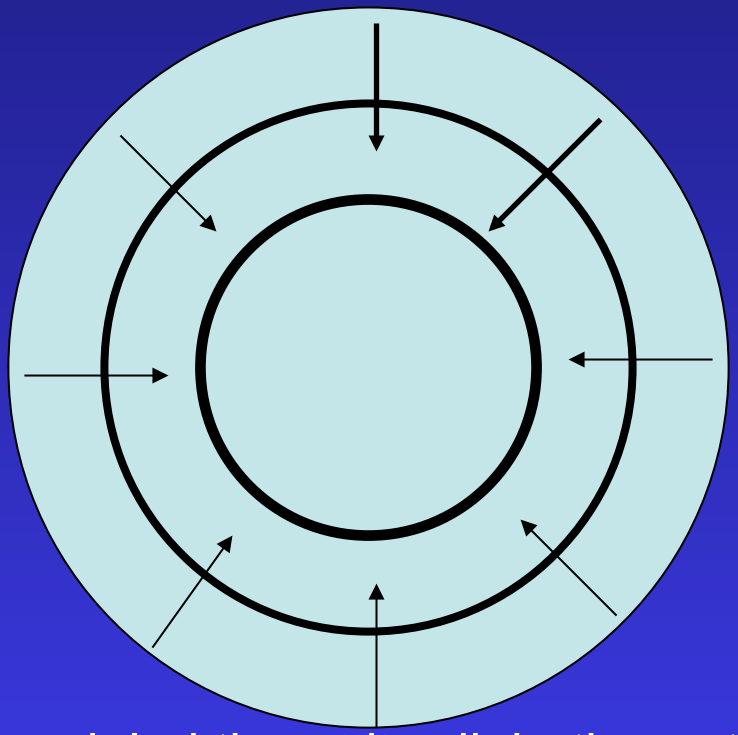
- Observational strategies

→ PISNe rate modification
→ Clustered (/ lensed) *capture* “Dark Stars”

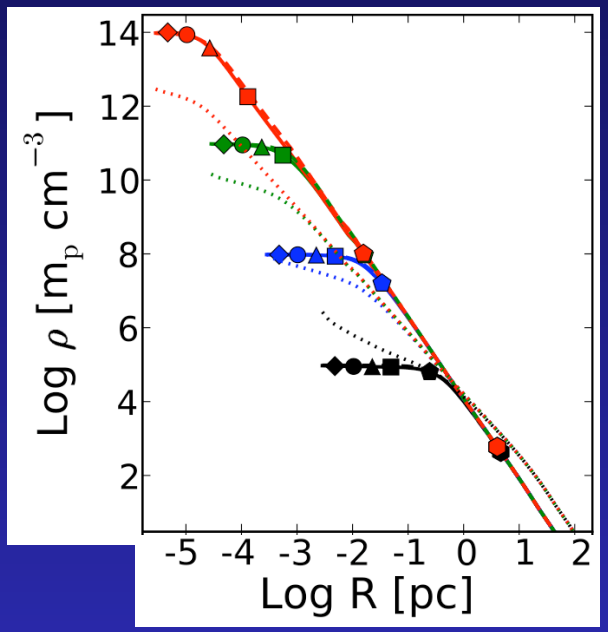
Gravitational Contraction

Gas collapse and build-up of the DM cusp

Gas (collisionally) cooling and collapsing to the center (gravitationally)"pulling in" embedded DM



(modeled through adiabatic contraction)



DM density up: energy production

$$\frac{dL_{\rm DM}}{dV} = \frac{\rho^2}{m_\chi}\langle\sigma v\rangle$$

Gas density up: higher opacity

$$* \kappa\,(n_{gas})$$

Energy repartition for WIMP annihilation:
1/3 electrons
1/3 photons
1/3 neutrinos (lost)

Feedback effects during protostellar phase

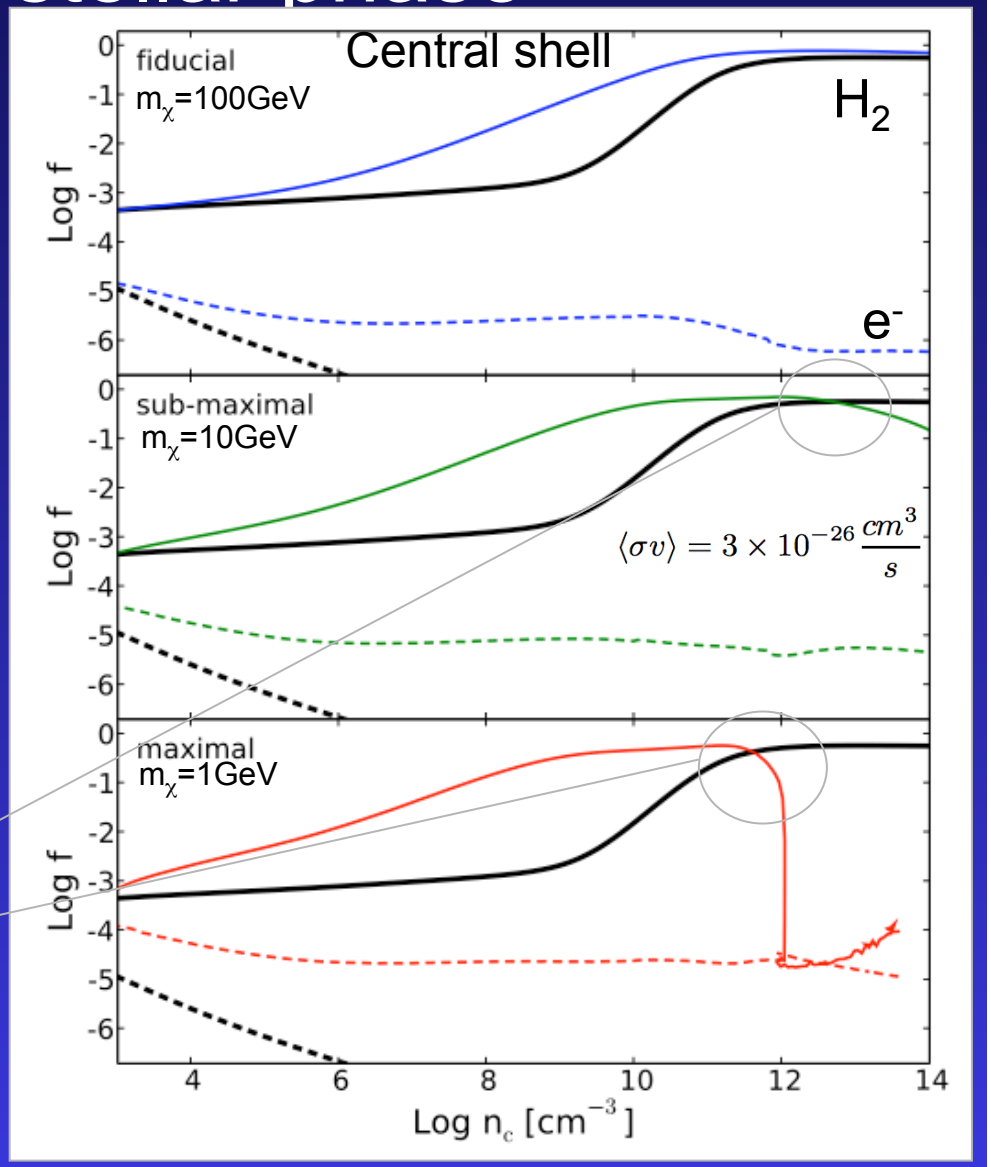
DM annihilation:
not only heating!!!
(Jonathan, you can ignore it)

DM annihil. induces ionizations
ionizations catalize H_2 formation
H_2 is a coolant : T down

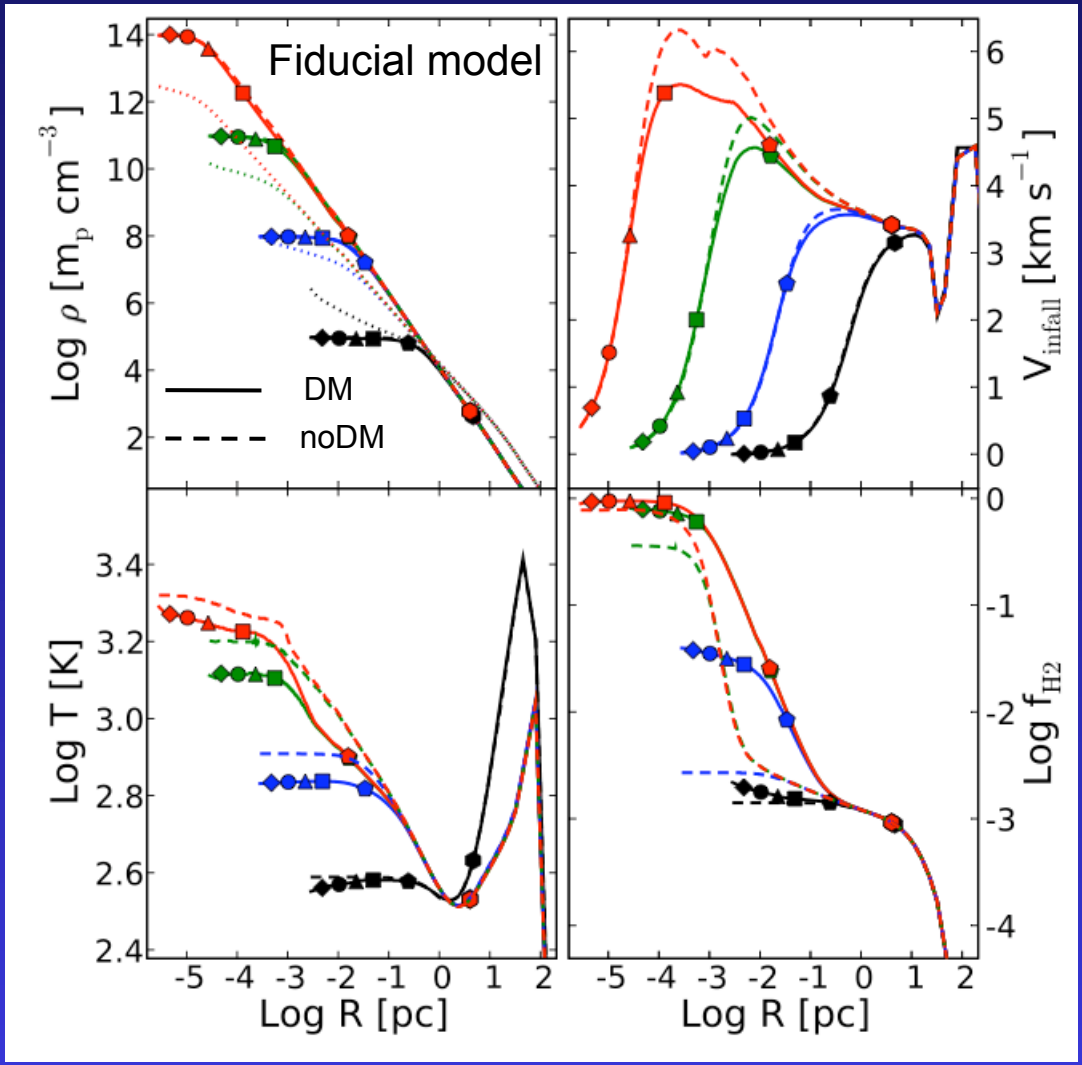
DM induced feedback dominates at
10^6 #/cm^3 < n_c < 10^{13} #/cm^3

$n_c > 10^{13}$ #/cm^3
H_2 gets dissociated by DM heating,
BUT…

[Ripamonti, FI et al `09, `10]



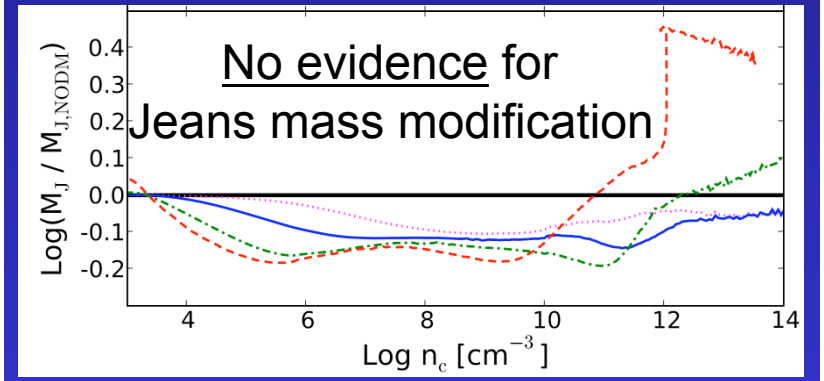
Feedback and *direct* DM effects
(in proto-stellar phase)



no dramatic change in
(gas/DM) density structure

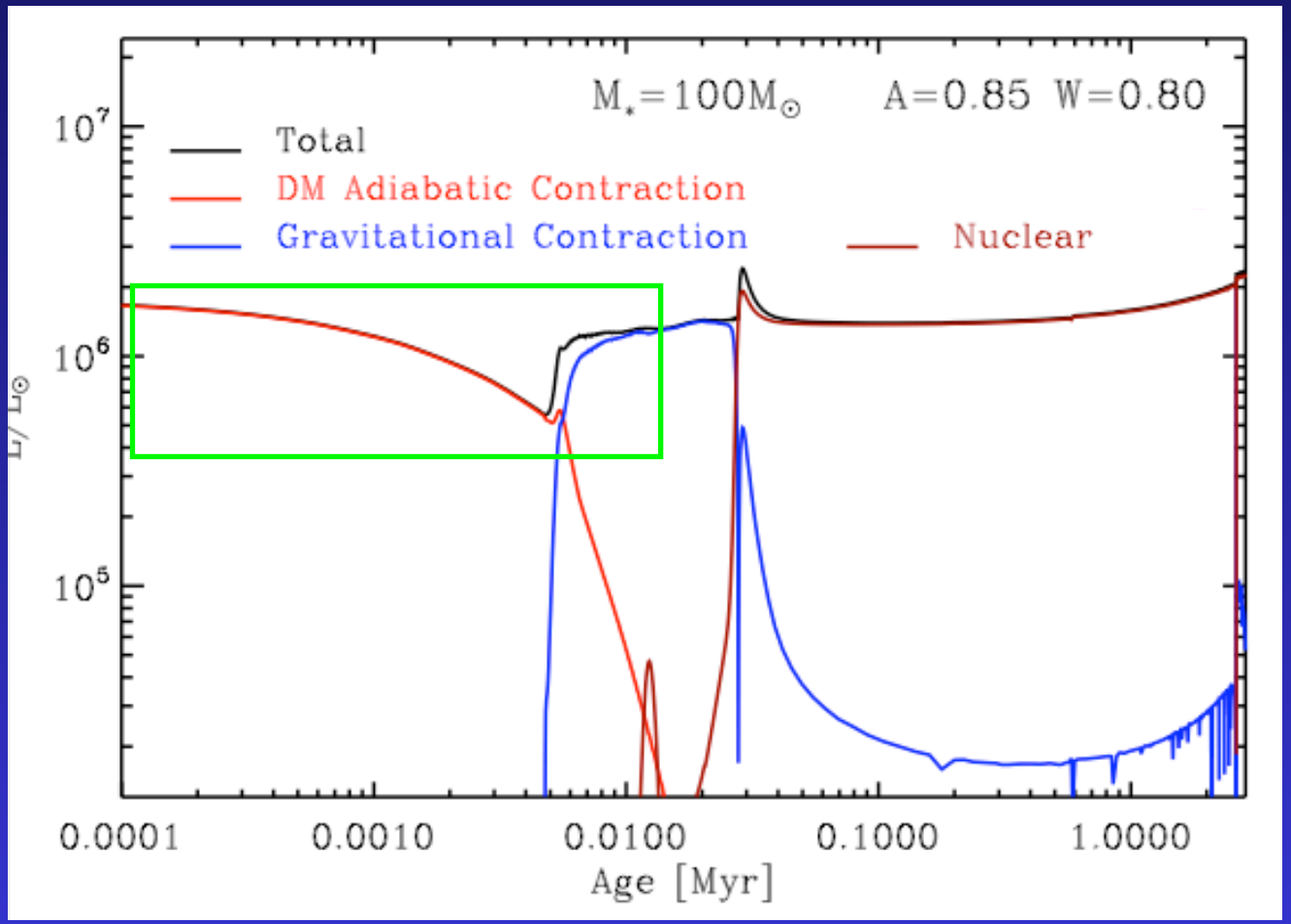
no dramatic change in
Temperature

no dramatic change in
infall velocity



[Ripamonti, FI, et al. `10]

Hydrostatic core + grav. contracting DM
without gas accretion



Grav. Contracting DM phase (AC) is short! ≈10^4yr

[Iocco et al '08]

Punchline of gravitational accretion mechanism

- During “early” stages, when yet no hydrostatic core

- Feedback dominates cloud property
  → No DM annihilation ionizes, H_2 up, T down
  → No dramatic decrease in T, no change in r, no change in v
  → No change of Jeans mass

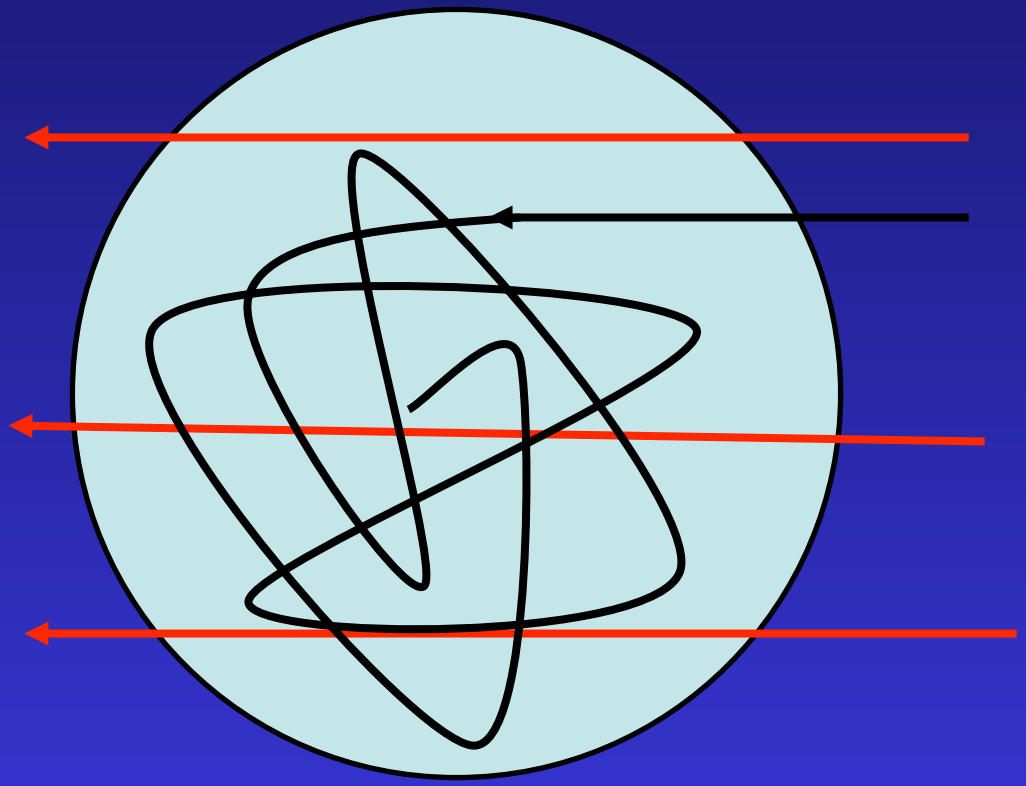
- Closer to hydrostatic core, direct heating from DM
  → continuum cooling dominates, no dramatic changes neither

- Hydrostatic core sustained by DM ann.

→ Unstable equilibrium, short transients
→ No evidence for supermasses build-up

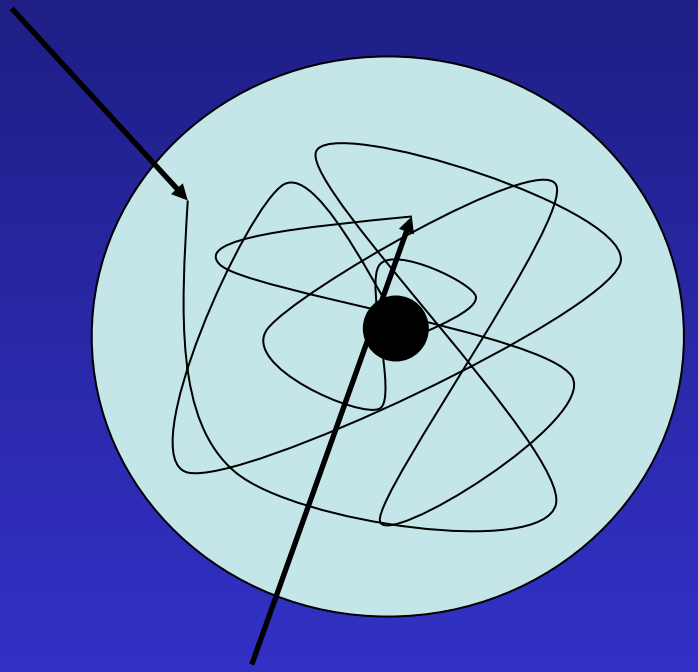
Scattering and capture

Halo WIMPs are captured



by scattering off the gas of the star

Captured WIMPs accumulate inside the star, thermalize



and “sink” to the center

Scattering and capture:

a continous process (needs refill)

Capture rate C

$$C \propto \frac{\sigma_0 \rho}{\bar{v}} \frac{M_*^2}{R_*} \frac{1}{m_\chi}$$

WIMPs thermally relaxed within the star: Distribution

$$n_\chi(R) = n_\chi^c \exp(-R^2/R_\chi^2)$$

WIMP annihilation ≈ point-source $R_\chi << R_c$

"Dark Luminosity" inside the star

$$L_{DM} = 4\pi \langle \sigma v \rangle m_\chi \int n_\chi^2(r) r^2 dr$$

At equilibrium

$$L_{\rm DM} = C m_\chi$$

Virtually no dependence from self-annihilation rate $\langle \sigma v \rangle$ BUT from σ_0

Equilibrium timescales are short close to ZAMS enormous otherwise

$$\tau_{\rm th} = \frac{4\pi}{3\sqrt{2G}} \frac{m_\chi}{\sigma_0} \frac{R_*^{7/2}}{M_*^{3/2}}$$

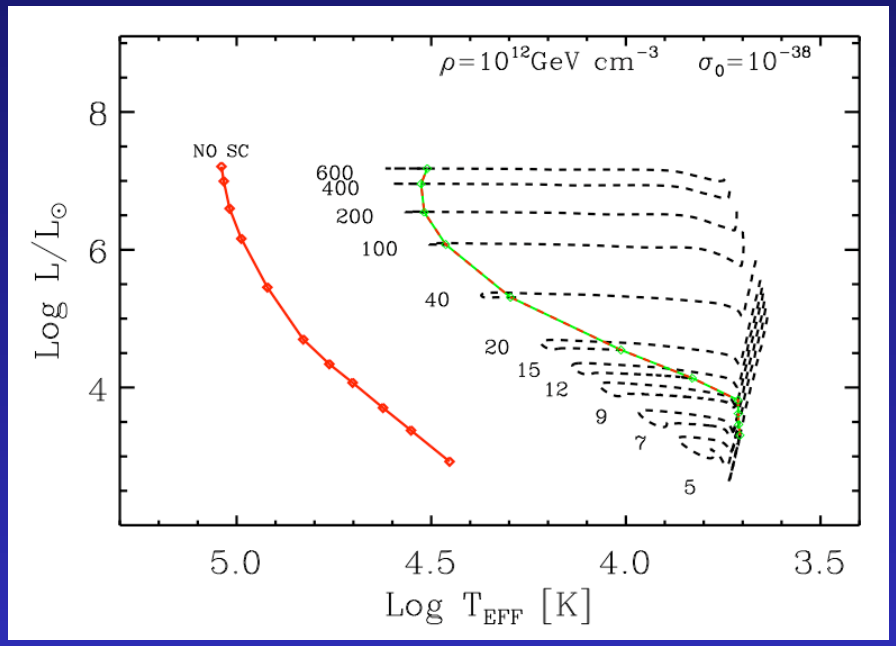
$$\tau_\chi = \left(\frac{\pi^{3/2} R_\chi^3}{C \langle \sigma v \rangle} \right)^{1/2}$$

Scattering & Capture:
main effects

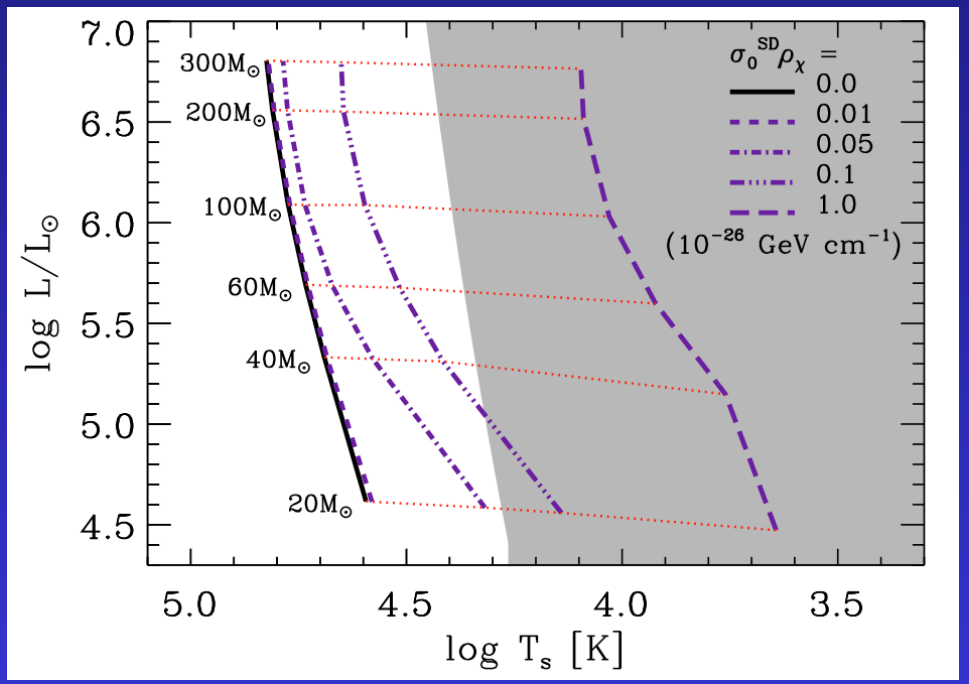
DM additional point-like source

STARS

EXPAND and cool down



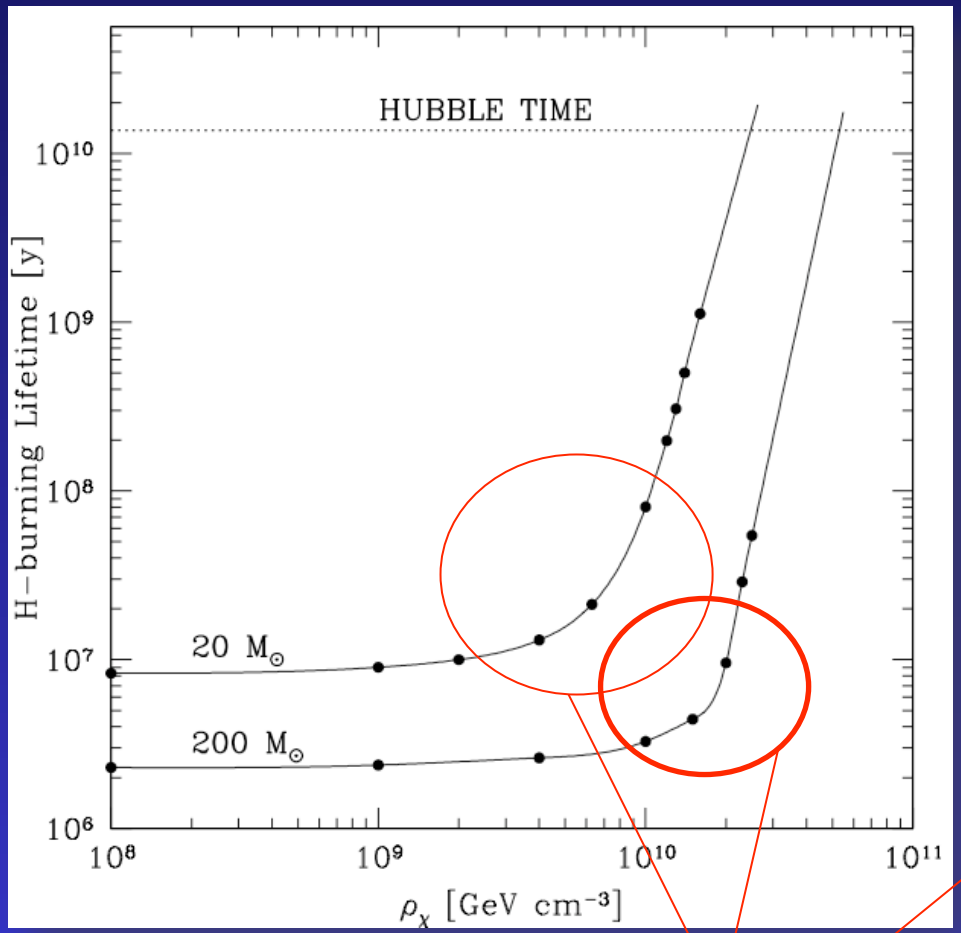
[Iocco et al. `08]



[Yoon, FI, Akiyama `08]

(the whole structure cools down, core included…)

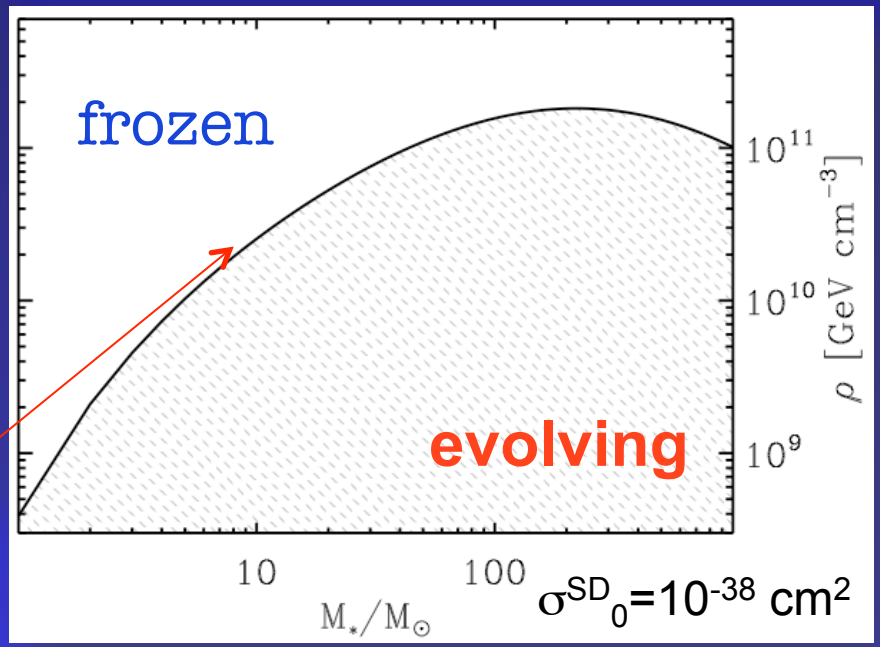
Scattering & Capture
(prolonging lifetimes)



[Taoso et al. `08]

DM powered
stars are "*frozen*"

as long as environmental DM stays supecritical

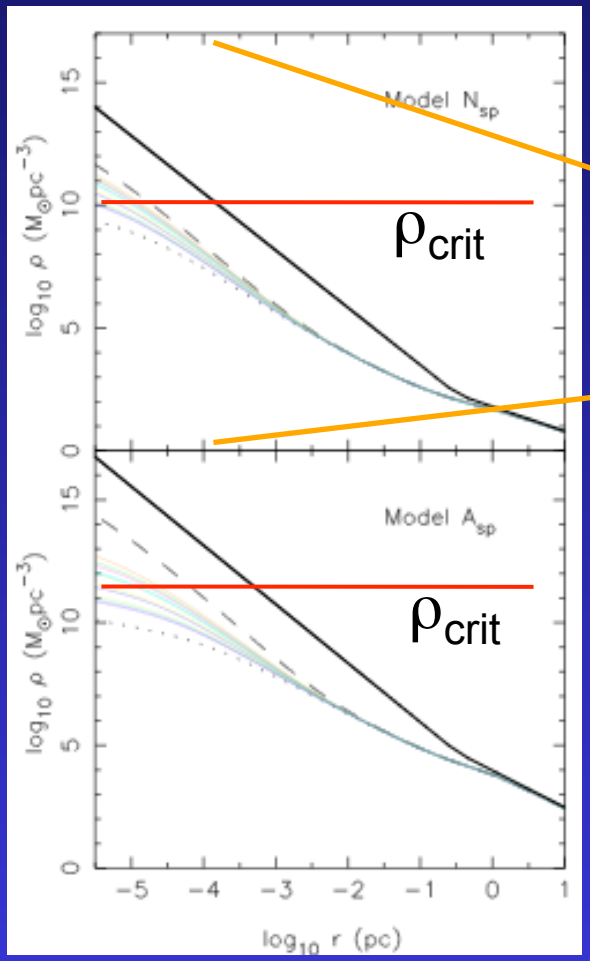


ρ_{crit} (M)

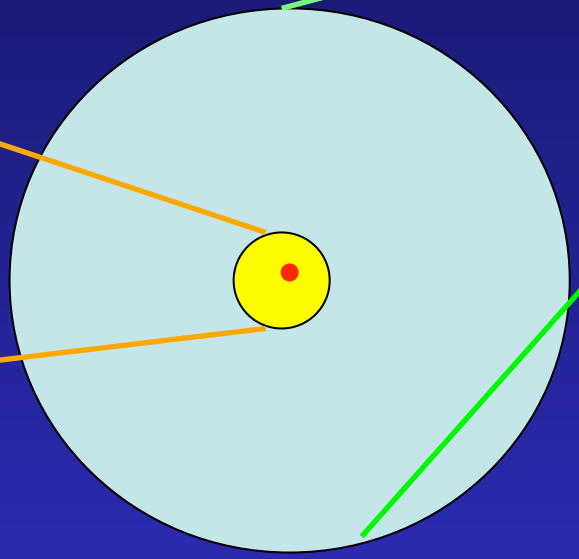
[Iocco et al. `08]

Direct observation

(surviving the ages-how much is $\Delta\tau$?)



[Bertone & Merritt `05]

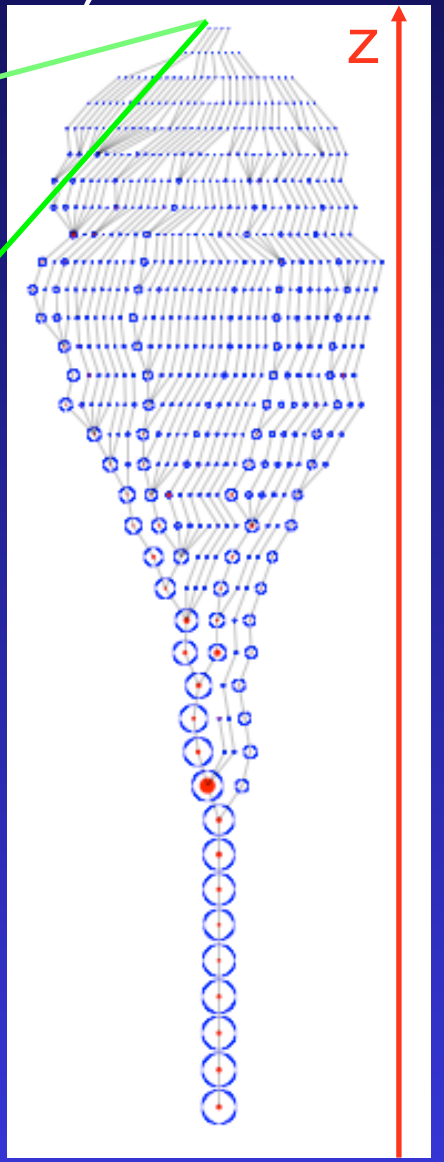


(not actual size)

Halo merger

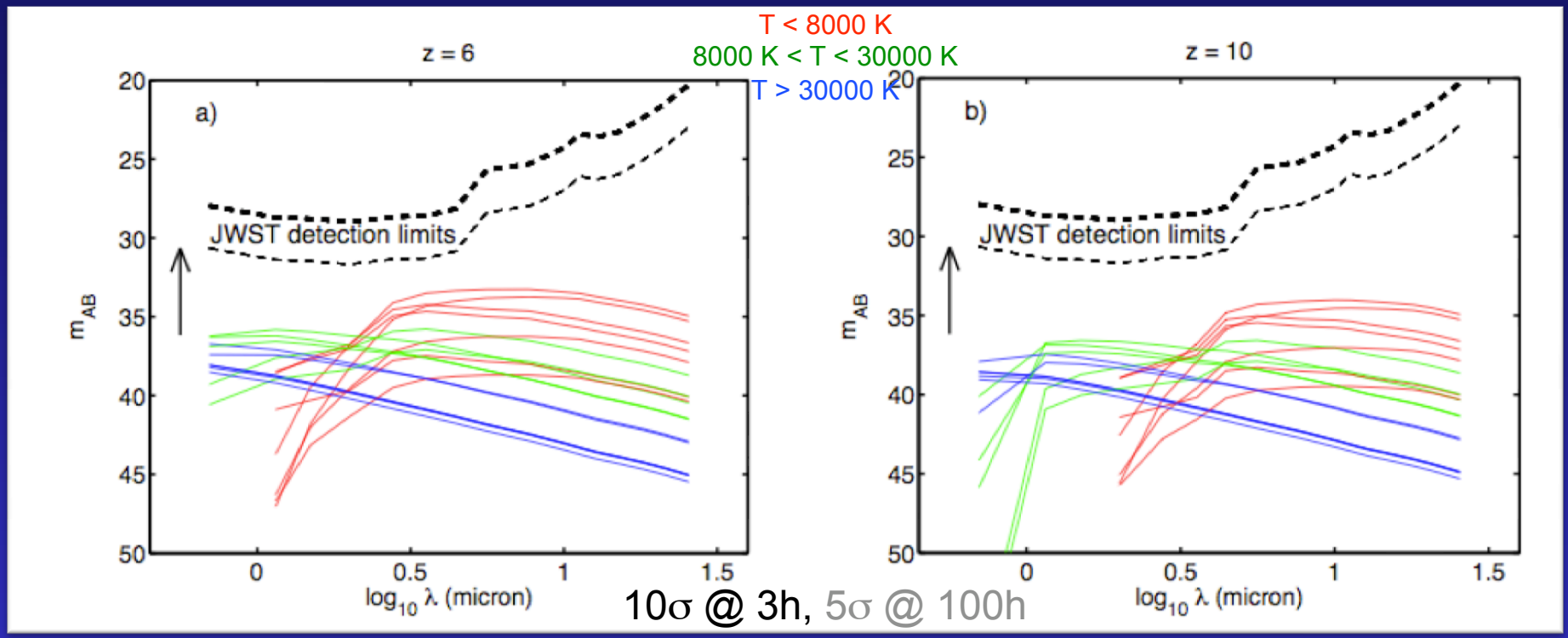
DM cusp erosion

(Baryons + self-annihilation)



[Wechsler et al `02]

Single DS Direct Observation?
(with JWST)



Real atmospheres vs Blackbody

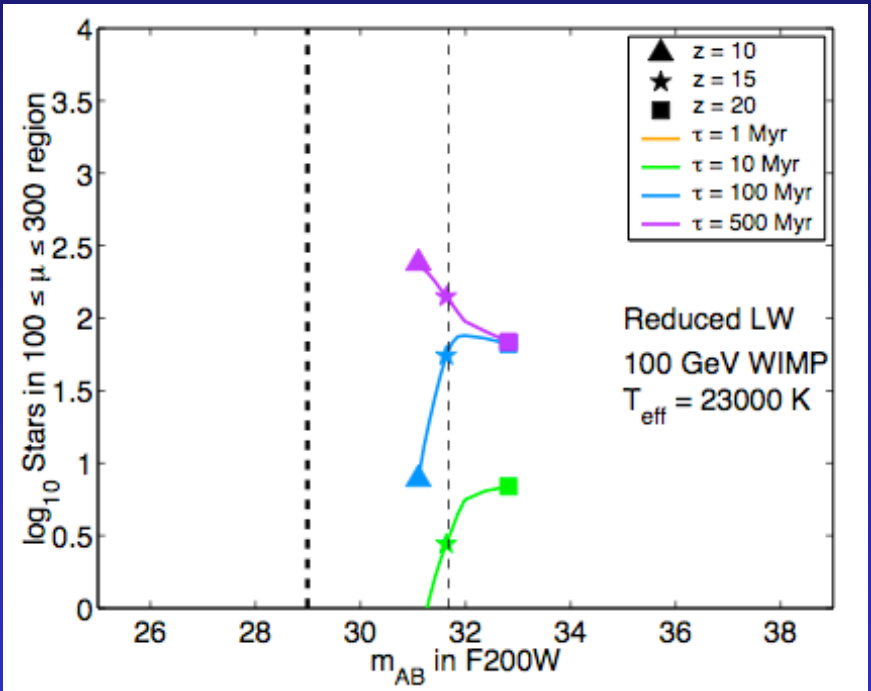
M_{DS} < 700 solmass

Massive **single** DS are

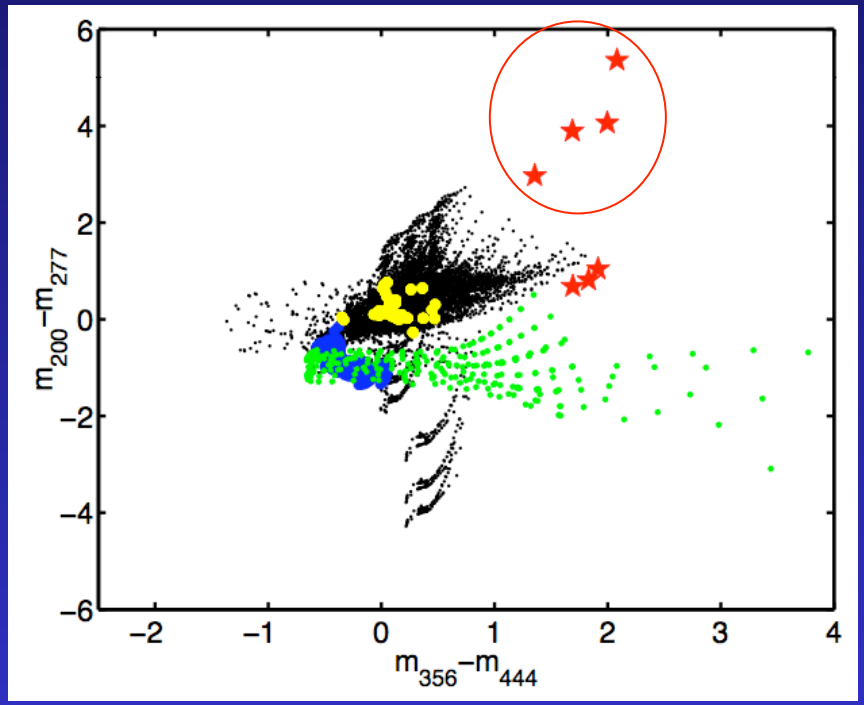
intrinsically too faint

for JWST detection [Zackrisson et al. `10]

Clustered DS
observation and discrimination



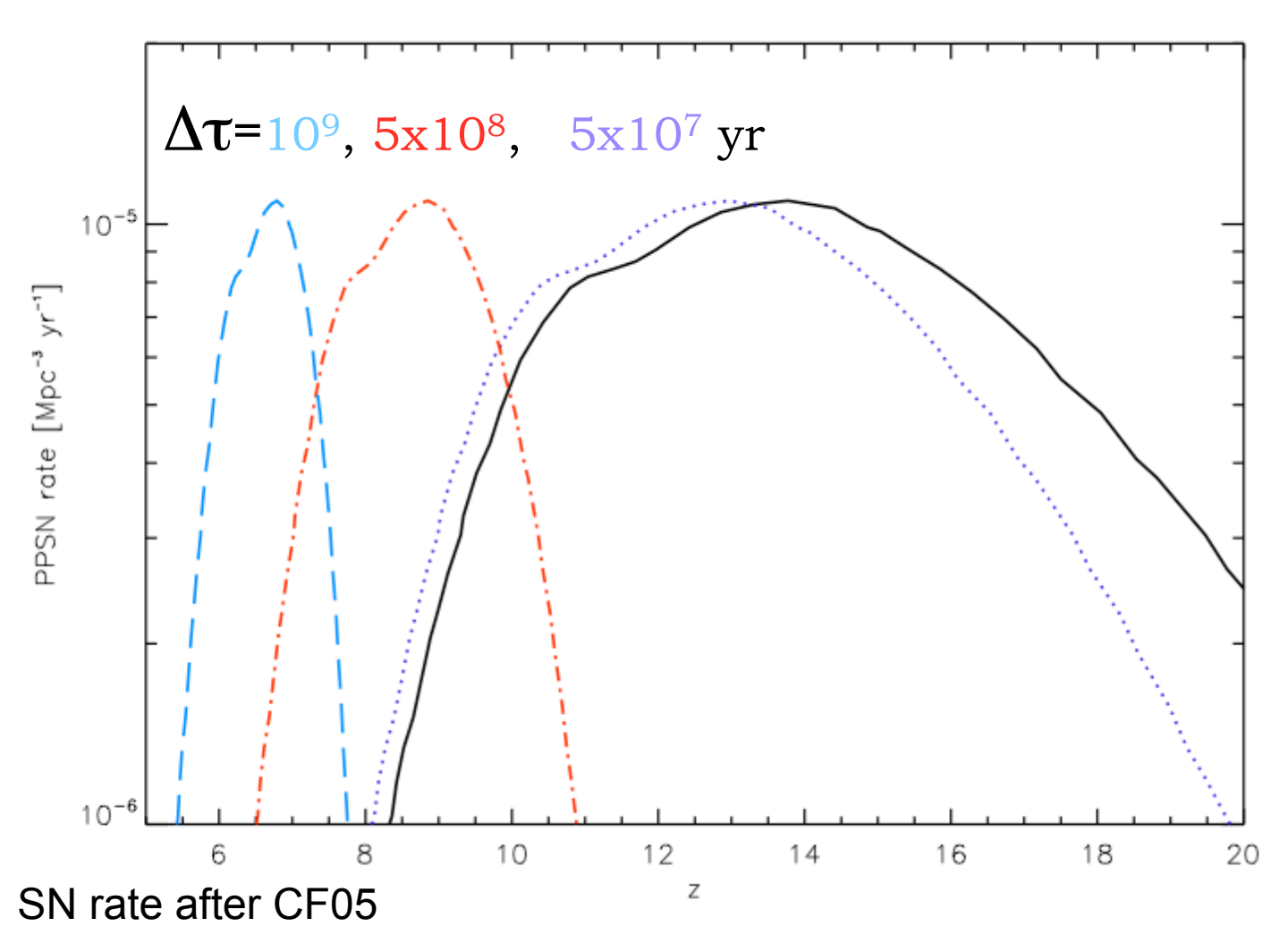
Enough objects can cluster,
if $\Delta\tau$ > 10 Myr
(depending on parameters)



Color-color characteristics!

[Zackrisson et al. `10]

A possible signature in the (PI)SNe rate?



SN rate after CF05

[Iocco `09]

Caveats

- Why you are skeptic about all this
(in A.L. notation: astrophysics)

- "Centering" of the object
- DM cusp needed
- Below resolution (sub-solmass DM)
- 1-D models (mostly semianalitical)

→ You can do something about it (3D High Res SIMs ☺)

- Why I am skeptic about this
(in A.L. notation: physics)

- DM is not necessarily WIMP
- if WIMP, yet σ_0 is most unknown (crucial for scattering)

→ We are in a relatively safe zone (trust the theorists?)

Conclusions

- Two phases, Gravitational vs Scattering DM “accretion”

- Gravitational accretion acts early
  - → No dramatic indirect nor direct effect
  - → No sensible Jeans mass modification
  - → No evidence for Supermassive star formation

- Capture by scattering (active around ZAMS)
  - → Lifetime prolongement (MUST stay in proper DM bath, DM parameters)
  - → Widespread effects on Population, need control over environment!

- Observational possibilities (tough, but no “no go”) @ $z < 10$
  - → Lensed, single *capture* objects
  - → Clustered *capture* objects

Apologies to Natarajan et al., Schleicher et al., Umeda et al.
Time is an evil tyrant

Supermassive Dark Stars?

No!

I have a beautiful explanation but it does not fit this slide

Current issues

- Formation of a cusp and accretion phase

→ What effect from the baryons on the DM innermost profile? (Need of simulations)

→ Feedback in star formation, is it really negligible?

- Capture phase resilience

→ Stability of the cusp against mergers, gas friction and self-annihilation (simulations)

→ Centering of the star (simulations)

- Widespread effects on Population

→ What the effects of different halos (and gas profiles) during the accretion phase?

→ Which is the “average” and “variance” of the halo behavior?

→ Feedback on stellar population?