Neutralino dark matter annihilation in the first stars

(Divertissement in D# major for stars & DM in the early Universe)

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GGI, Firenze, 11/2/09

The first stars (Population III)

Form in halos of $M_h \approx 10^6 M_{sun}$ at $z \approx 20$ ($T_{vir} < 10^4$K)

First Stars $\Rightarrow$ primordial chemical composition
(BBN: no C,N,O -- A > 7)

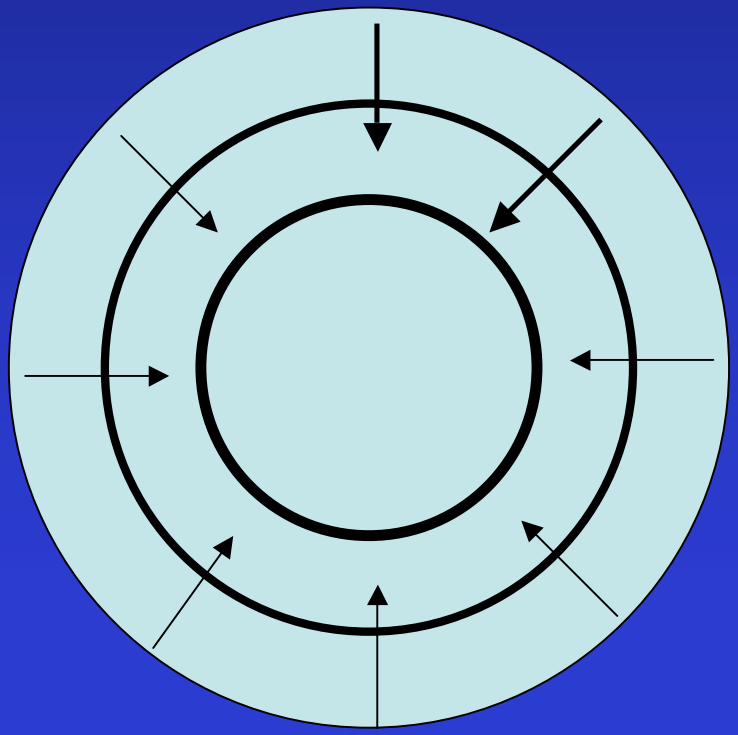
Weak cooling: H_2 vs CO $\Rightarrow$ big masses
Smooth collapse, at the center of the halo
No fragmentation, one star per halo
Live fast, die young (30-300Msun go SNe)
Hot: first engines for IGM Reionization
(possibly) seed BH, correlated to quasars

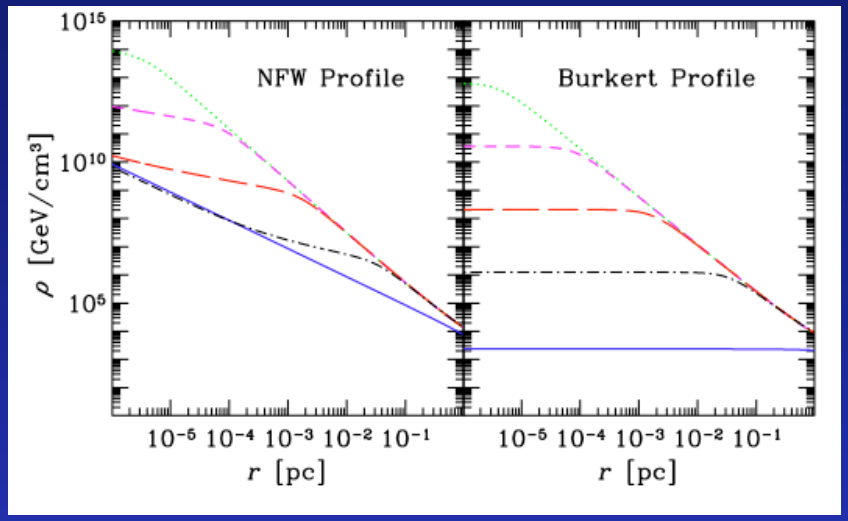
$$M_J \propto T^{3/2}$$

As of now, we have
(very likely) not seen one yet

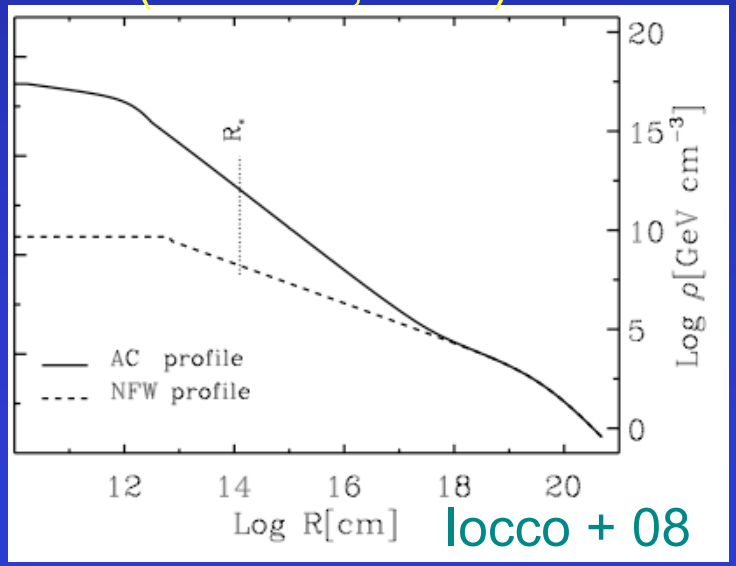
Building the DM cusp

Gas (collisional) cooling
and collapsing to the center
"pulling in" DM (gravitationally)
(modeled through adiabatic contraction)





Spolyar, Freese & Gondolo 07
(PRL 100, 2008)



Iocco + 08

(also Freese+ 08)

Powering the structure (with DM)

Energy production

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

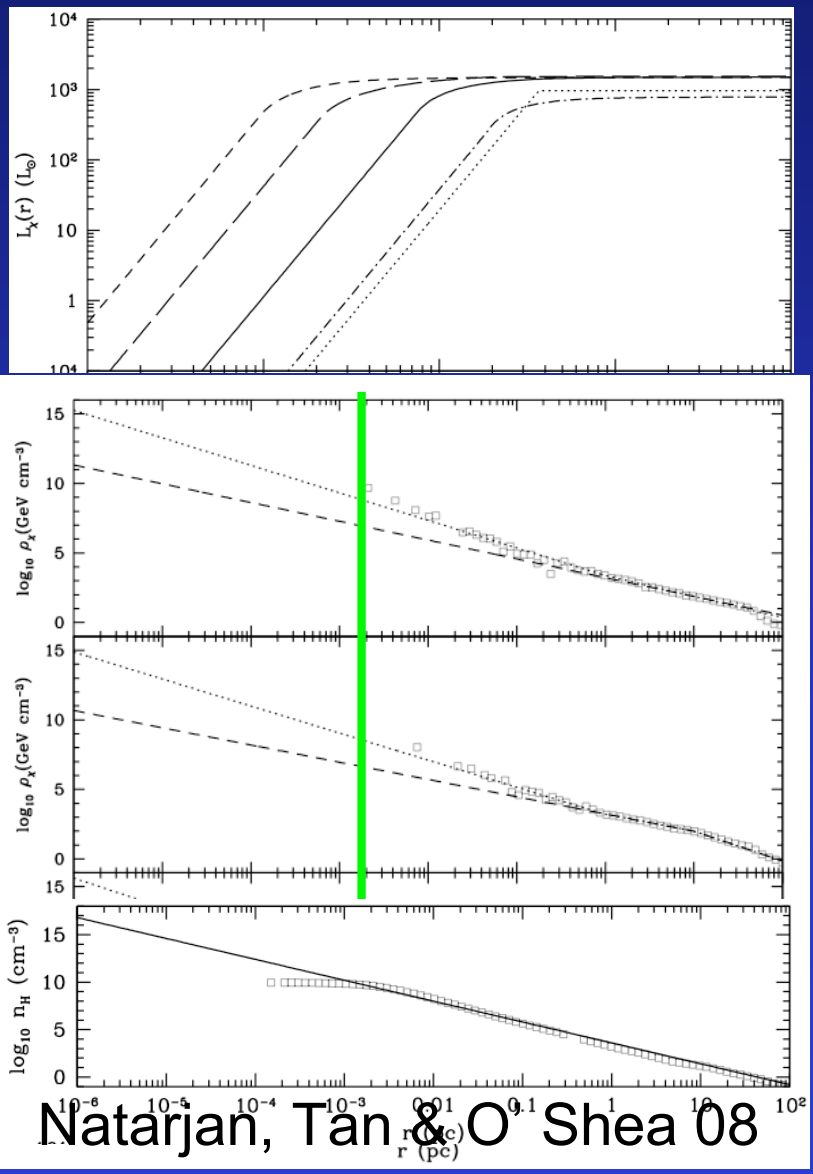
DM profile critical!

+

Energy deposition

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

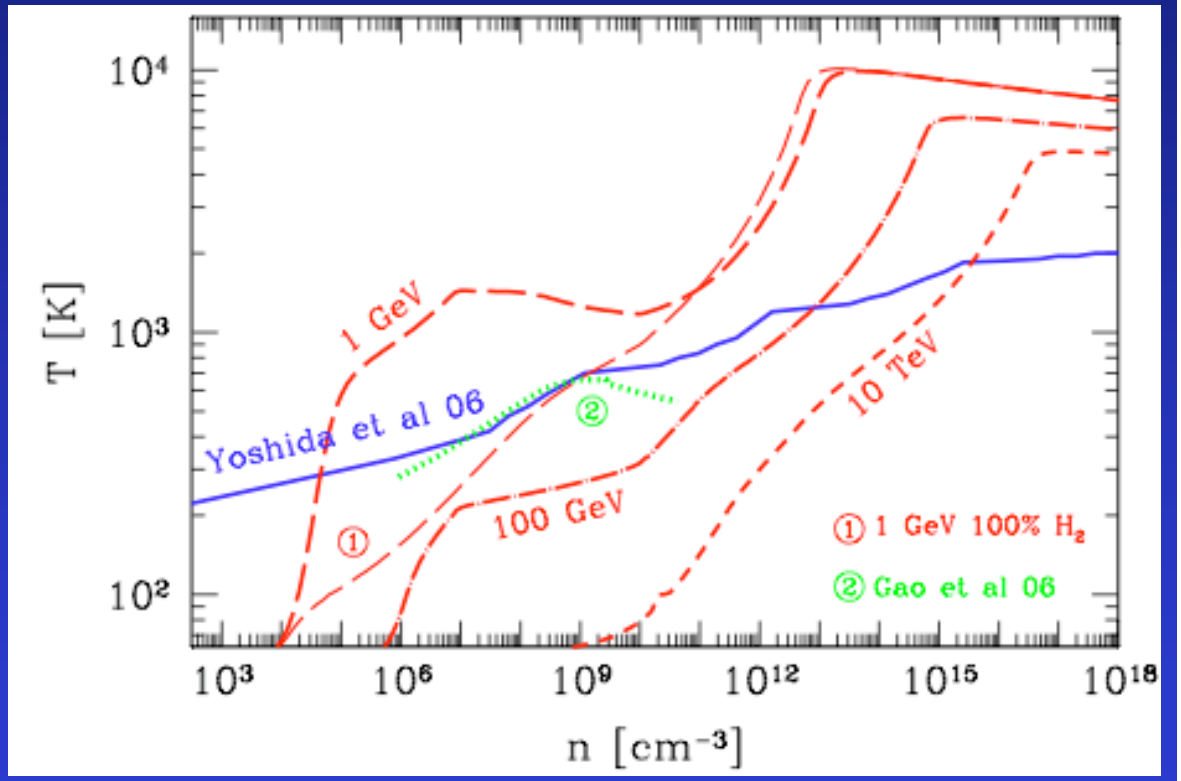
Absorption:
Gas profile critical!



Natarjan, Tan & O'Shea 08

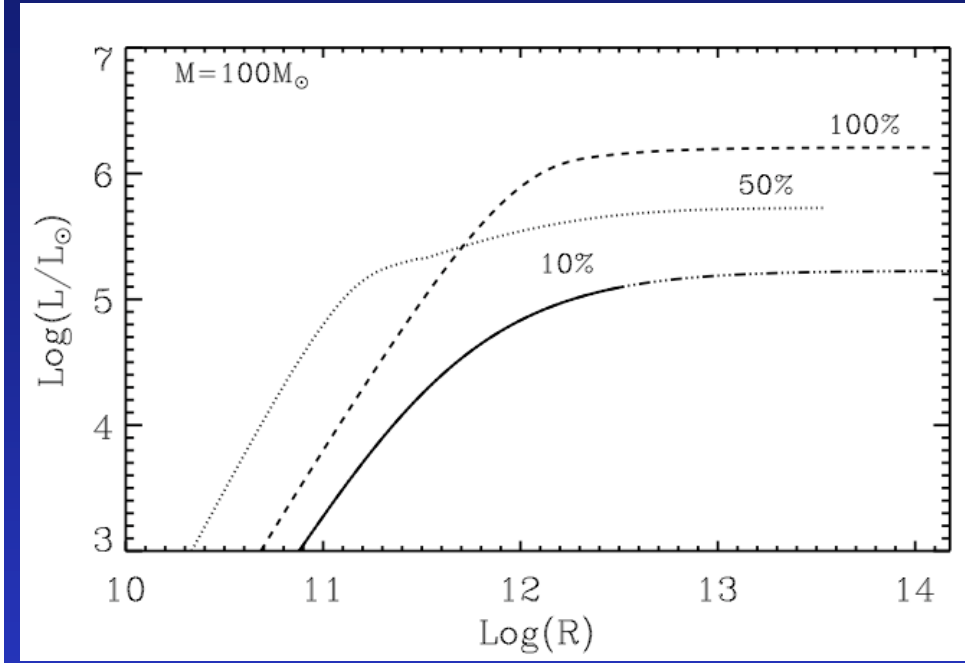
(only) *first stars can do it !*

At n_{gas}~10^{12} #/cm^3
(and above)
structure opaque
to annihilation products

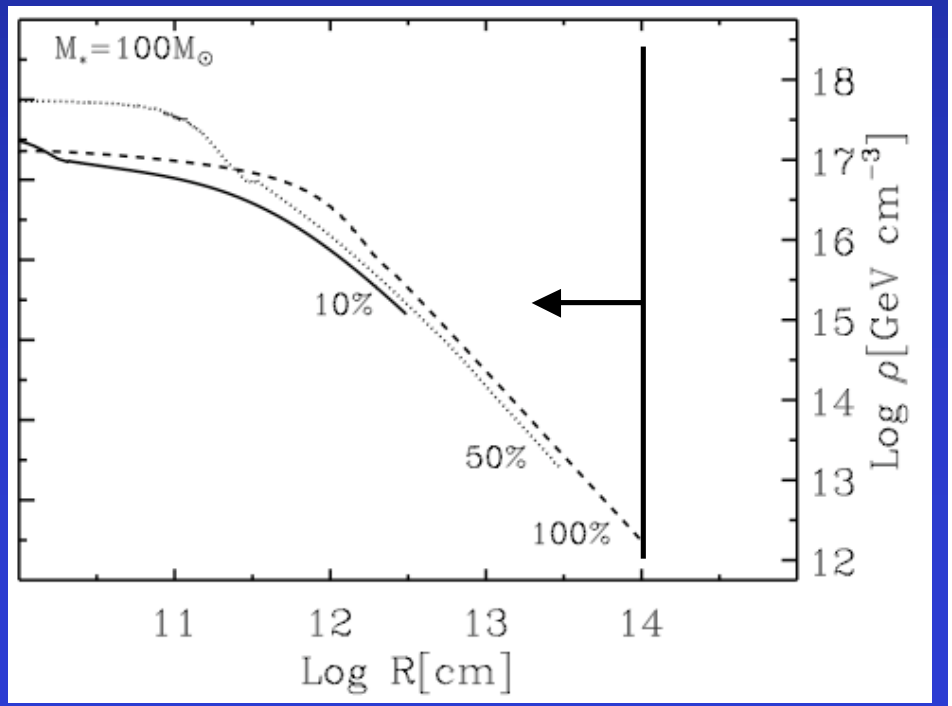


Spolyar, Freese & Gondolo 07
(PRL 100, 2008)

So what?



100 Msun
initial conditions:
$R=10^{14}$cm
$n_{gas}=10^{16}$ #/cm3



delicate equilibrium
between accretion
(or DM cusp build-up)
and annihilation

Iocco, et al., MNRAS 390, 2008

Dark Star (à la Freese)

Polytropic EoS for the gas

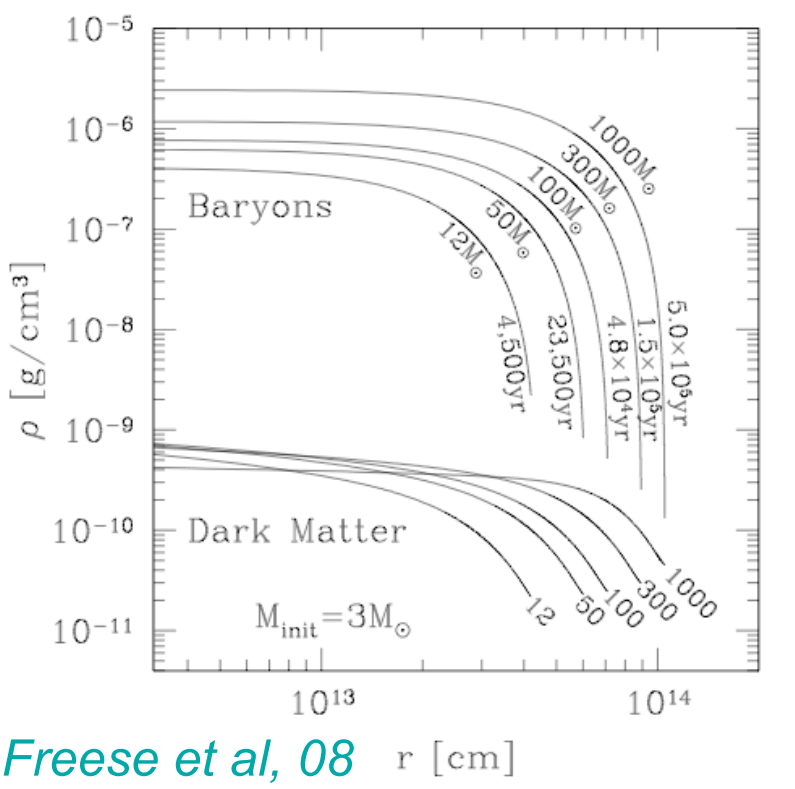
Mass accretion≈10^{-3}Msun/yr

T≈10^5 K, t≈10^6yr, R≈10^{14}cm

Long timescales, accretion of SMBH
While gas structire sustained by DM (?)

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

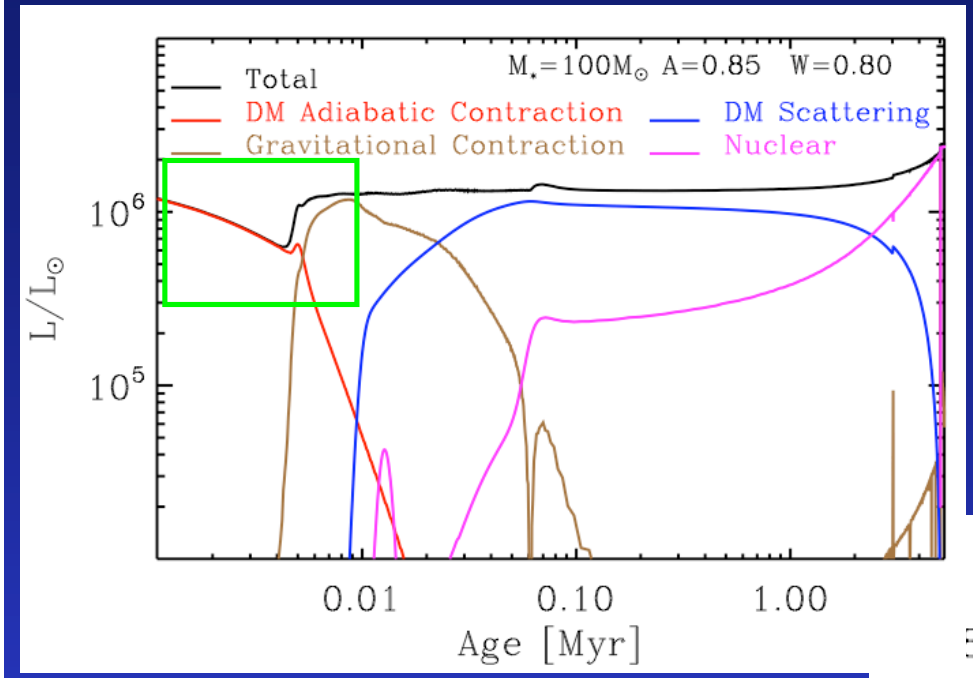
$$m_\chi = 100GeV$$
$$\langle\sigma v\rangle = 3\times10^{-26}\frac{cm^3}{s}$$



Freese et al, 08

M_* ($M_\odot$)	T_c (10^5K)	R_S (10^{13}cm)	ρ_c (gm/cm^3)	$\rho_{\chi,c}$ (gm/cm^3)	L_* ($L_\odot$)	T_{eff} (10^3K)	M_{DM} (gm)	t (yr)
12	1.3	4.2	4.1×10^{-7}	1.1×10^{-9}	1.1×10^{5}	4.3	2.8×10^{31}	6×10^{3}
50	2.7	6.0	6.2×10^{-7}	1.2×10^{-9}	4.2×10^{5}	5.0	9.1×10^{31}	2.5×10^{4}
100	3.5	7.1	7.7×10^{-7}	1.1×10^{-9}	7.8×10^{5}	5.3	1.6×10^{32}	5×10^{4}
300	5.3	9.0	1.2×10^{-6}	8.2×10^{-10}	1.9×10^{6}	6.0	3.6×10^{32}	1.5×10^{5}
1000	8.5	10	2.4×10^{-6}	4.5×10^{-10}	3.9×10^{6}	6.6	7.3×10^{32}	5×10^{5}

Evolving "Dark Stars"



Adiabatic Contraction phase
Acts at proto-stellar stages
(or early pre-MS)
at T≈ 5000 K

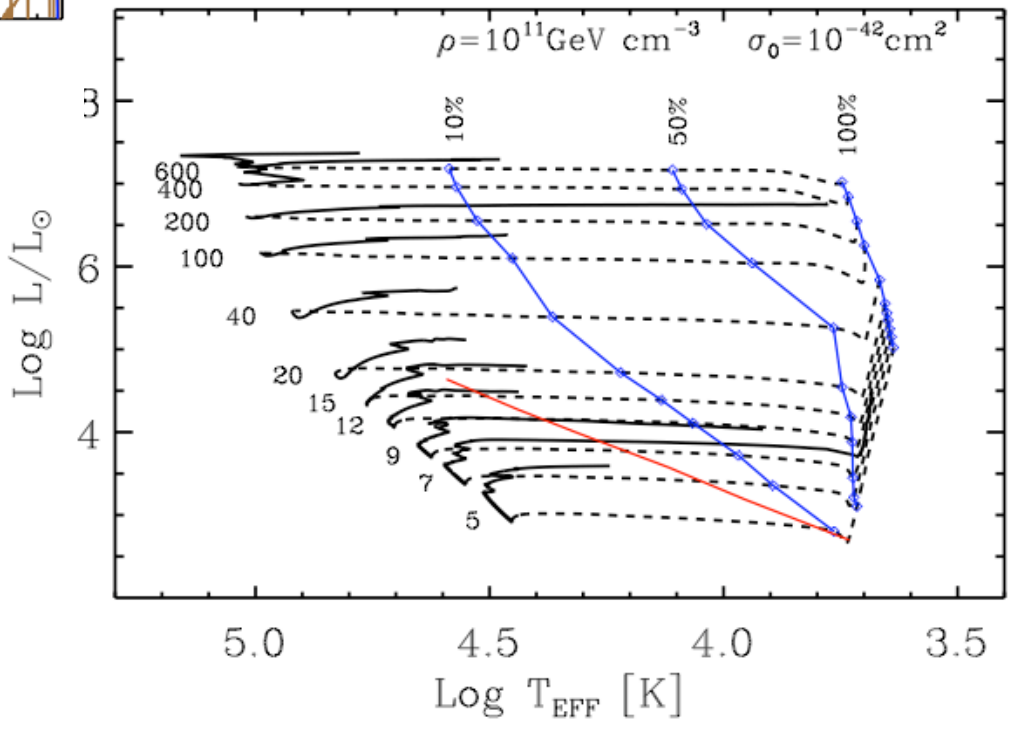
Adopted
fiducial values:

$$\langle \sigma v \rangle = 3 \times 10^{-26} \frac{cm^3}{s}$$

$$m_\chi = 100 GeV$$

(m_χ=200GeV, shorter times)

Iocco +, MNRAS 390, 2008



AC: a transient phase

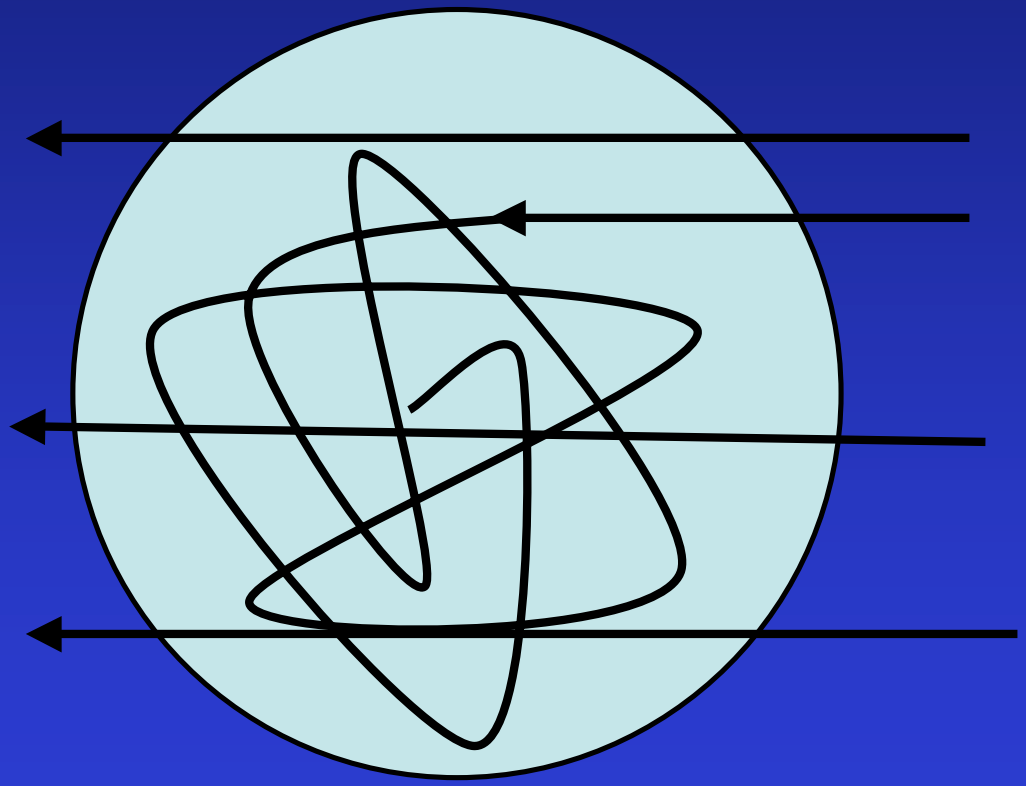
(παντα ρει και ουδεν μενει)

All groups seems to agree!

(aside details)

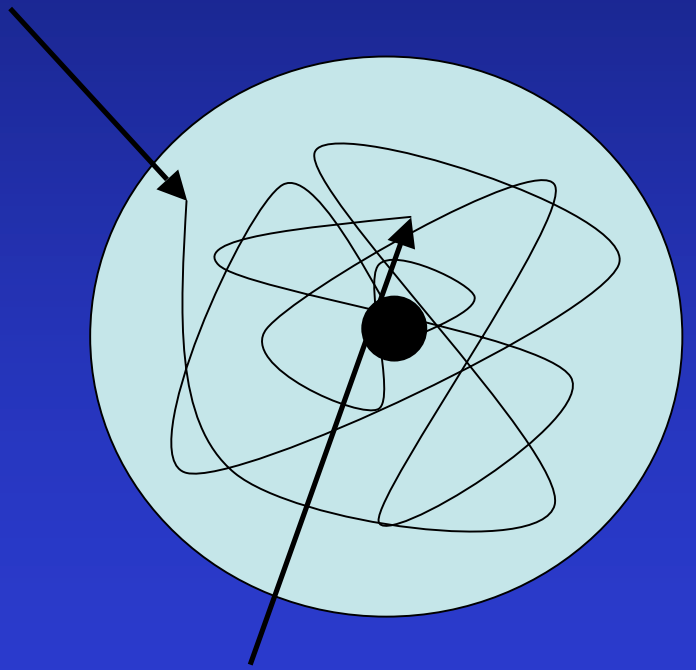
Scattering and capture

Halo WIMPs (originally outside the star) are captured



by scattering off the gas of the star

Captured WIMPs accumulate inside the star, thermalizing (need some time)



“sinking” to the center (most of annihilations is there)

DM and stars: scattering and capture

Capture rate C

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

"Dark Luminosity" inside the star

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

WIMPs thermally relaxed within the star

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

At equilibrium

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

Weak dependence on self-annihilation rate <σv>

WIMP annihilation ≈ point-source $R_\chi \approx 10^9 cm < R_c$

Equilibrium timescales

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

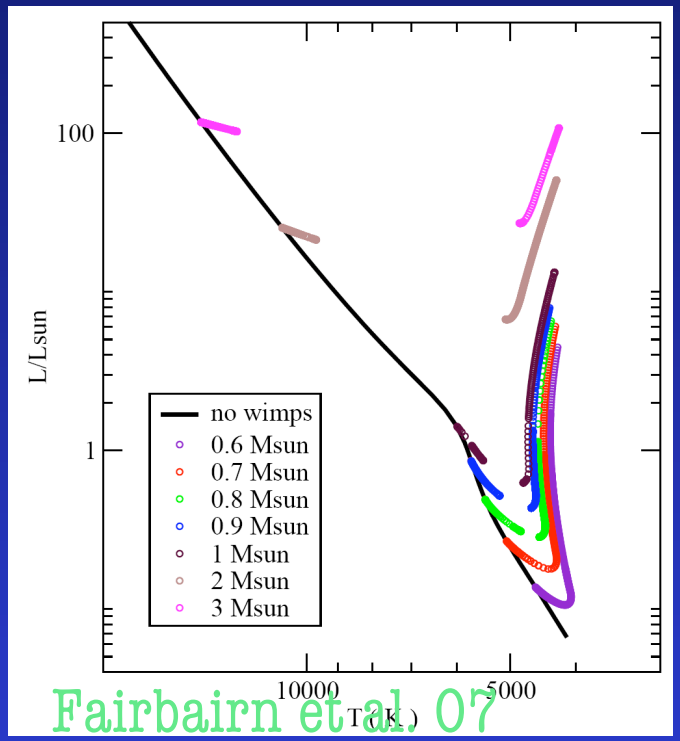
$$\tau_\chi = \left(\frac{\pi^{3/2} R_\chi^3}{C \langle \sigma v \rangle} \right)^{1/2}$$

At ZAMS $t_{kh} >> \tau_{th} > \tau_\chi$

Seminal literature by: Gould, Griest, Press, Raffelt, Salati, Seckel, Spergel

DM burning

Stars have negative specific heat:
feed them with energy,they will cool down

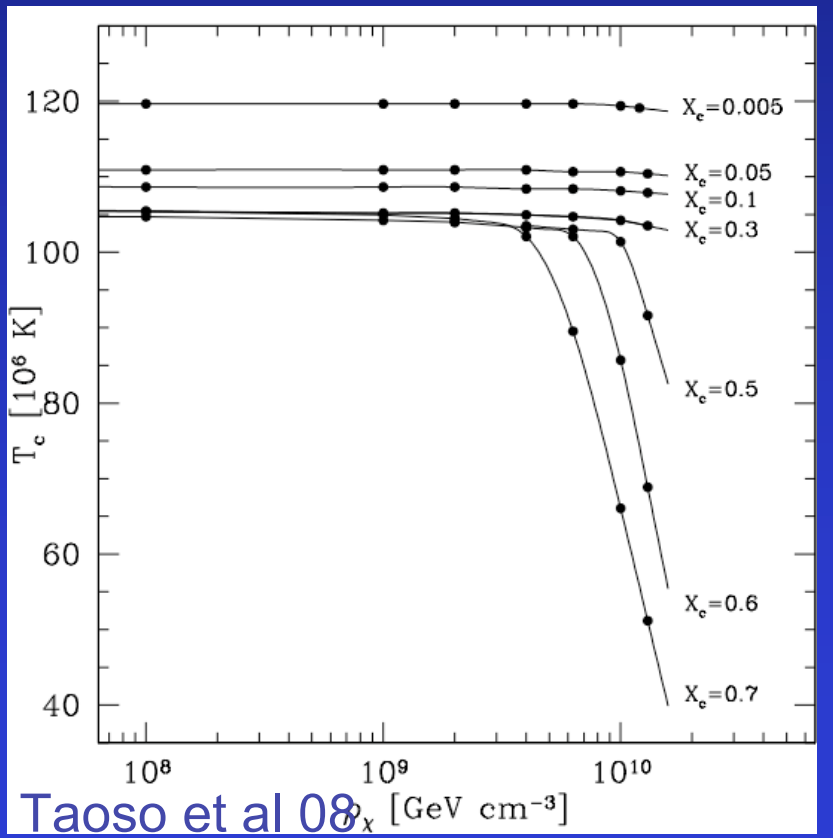


Fairbairn et al. 07

"Cool things start happening at about 10^8GeV/cm^3"
($\sigma_0=10^{-38}$cm^2)
M. Fairbairn

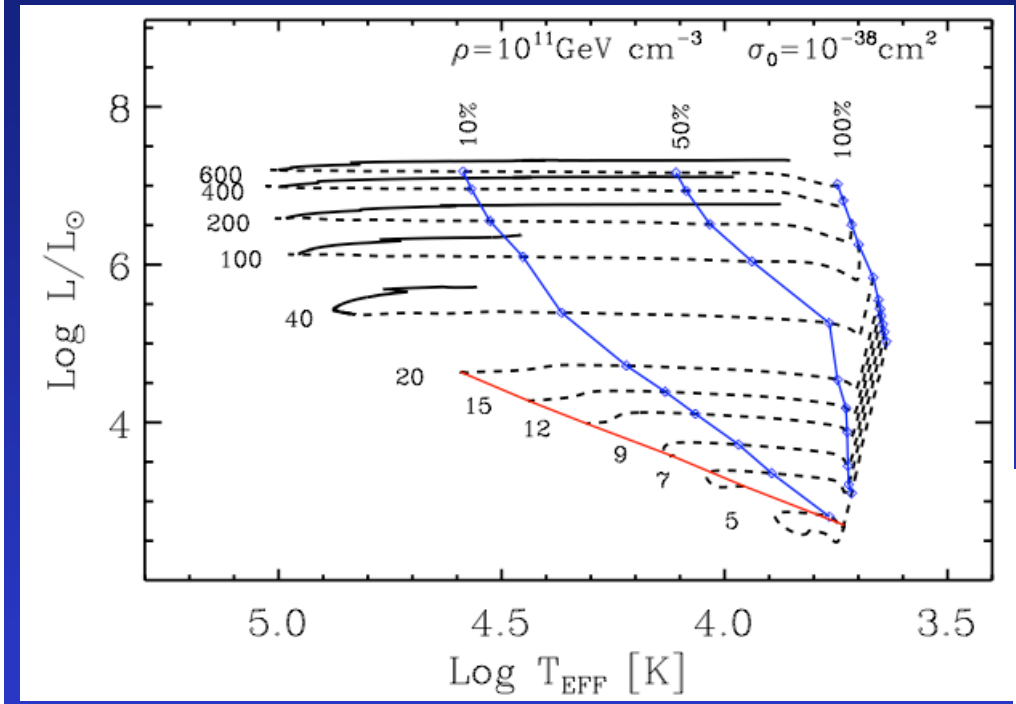
Scott et al. 08 for a detailed analysis of DM & stars at the GC

Nuclear burning switch-off (take-over of DM)

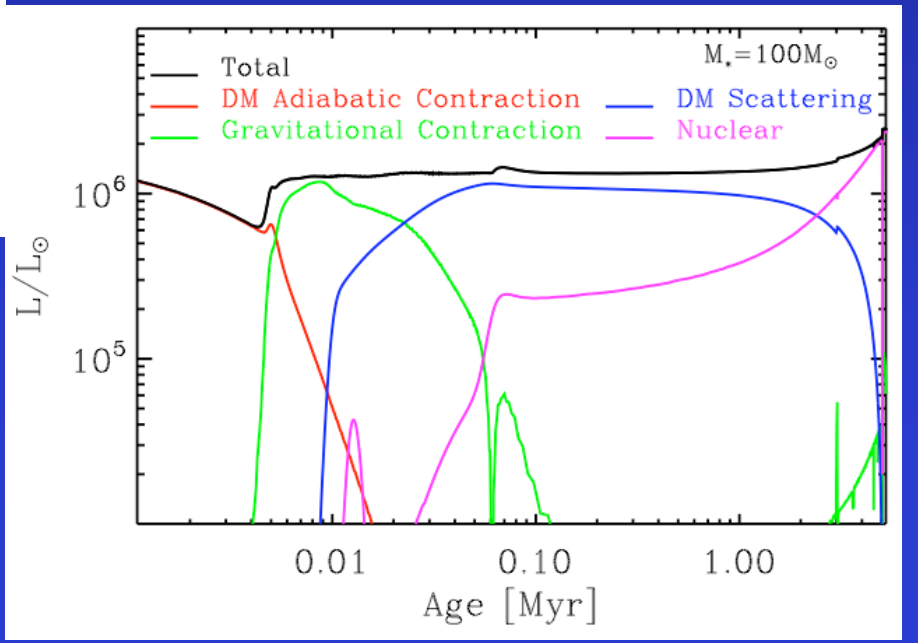


Taoso et al 08

So what, once they become "DM burners" ?



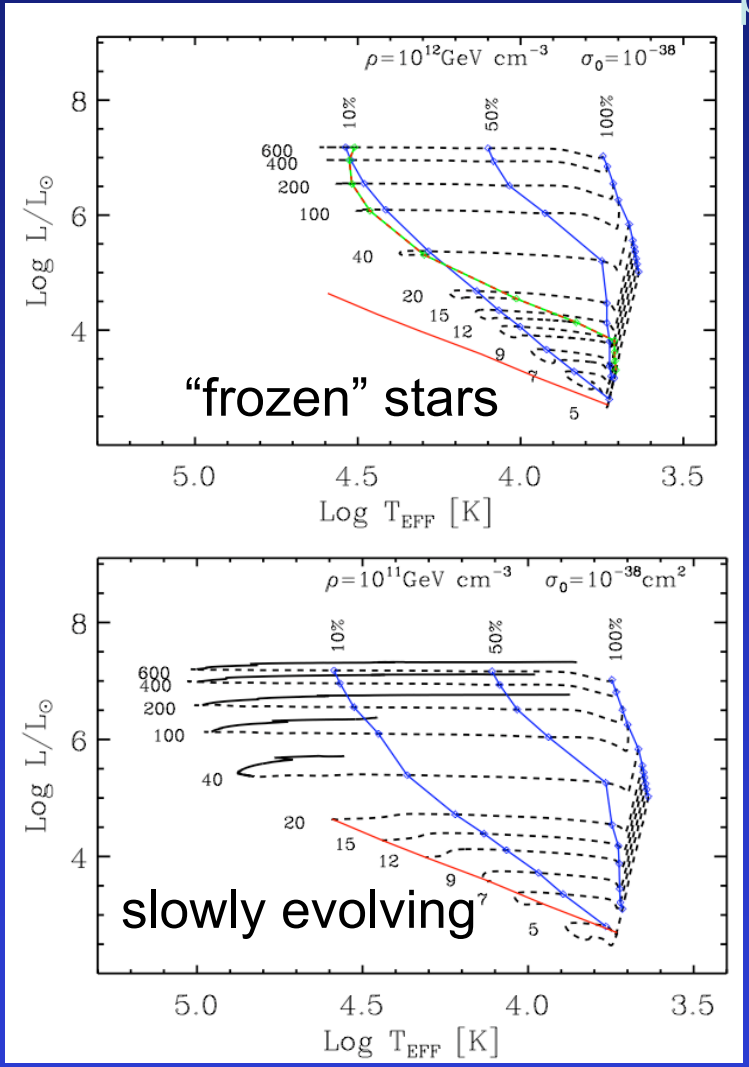
Active in late stages of pre-MS on Hayashi track $\tau_{KH} < \tau_{DM}$

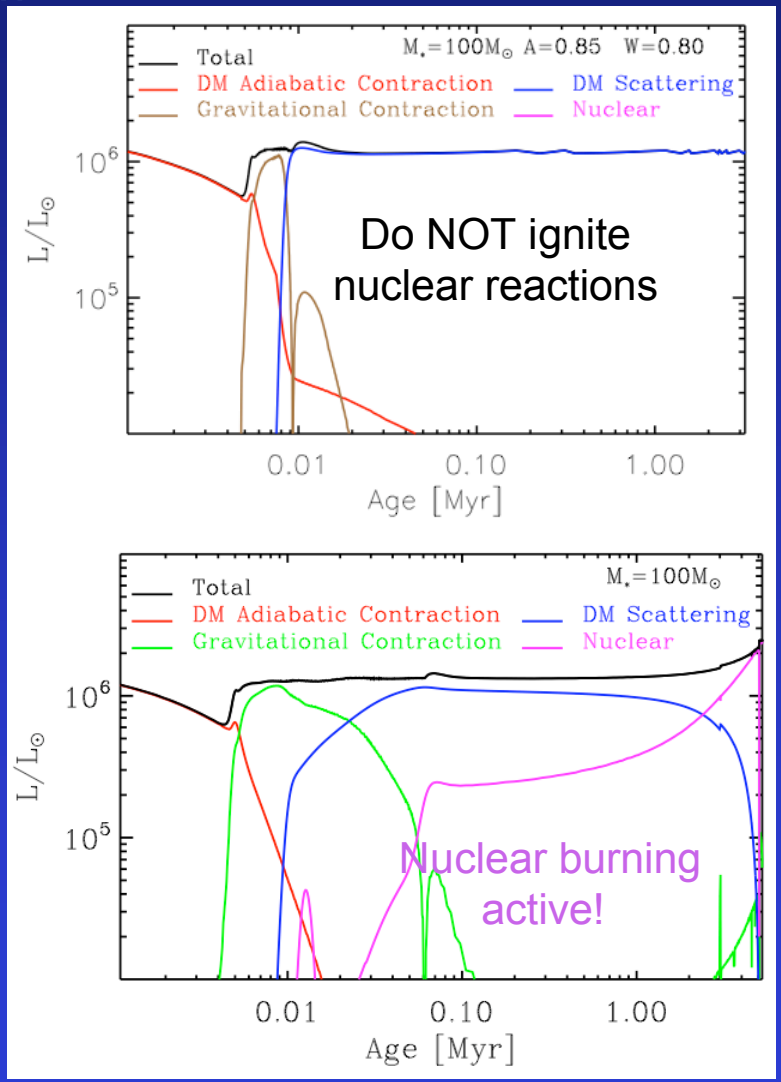


Iocco, Bressan, Ripamonti, Schneider, Ferrara, Marigo; MNRAS 390, 2008

DM burning: effects on the pre-MS

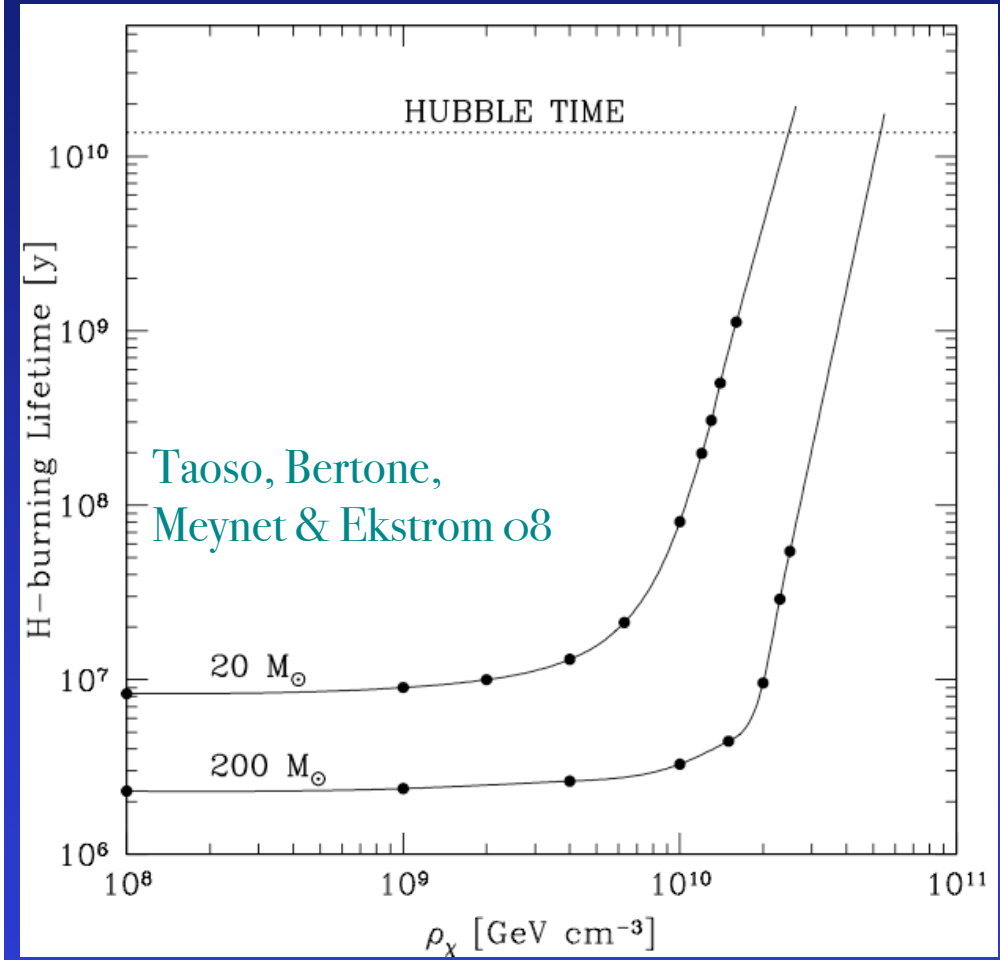
During AC phase $100M_{sun}$
$R=1.2\times10^{14}$cm, $L_X\approx10^{37}$erg/s,
$\rho_X=10^{12}$GeV/cm^3
$\tau_{th}>>t_{KH}$





Iocco, et al., MNRAS 390, 2008

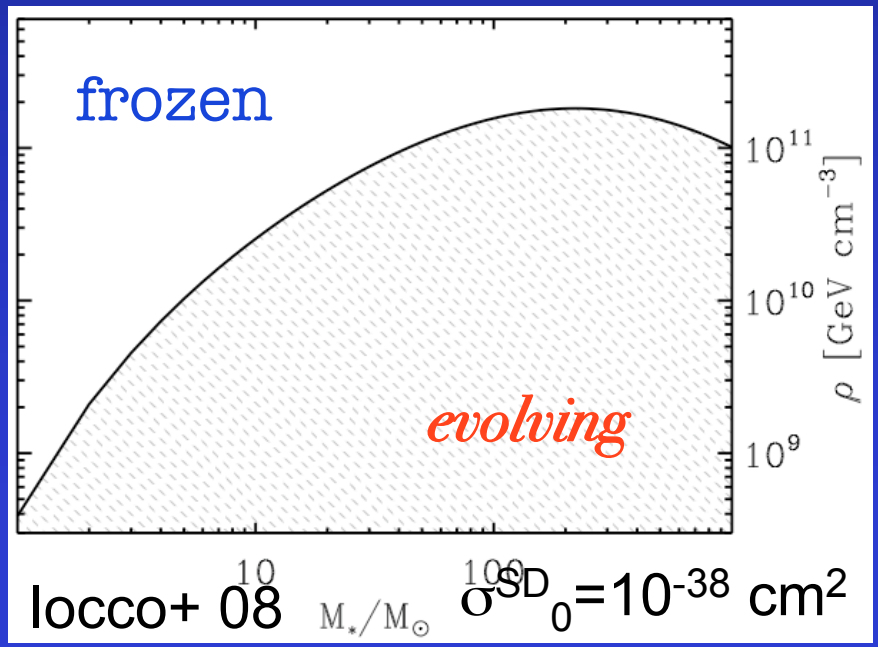
Prolonged lifetimes



Taoso, Bertone, Meynet & Ekstrom 08

DM powered stars are "*frozen*"

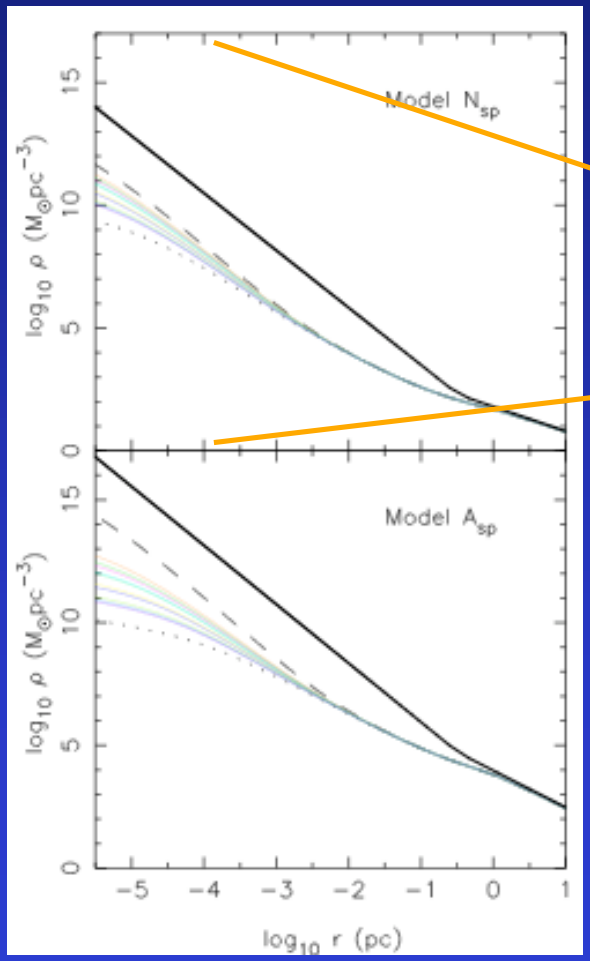
as long as environmental DM stays supecritical



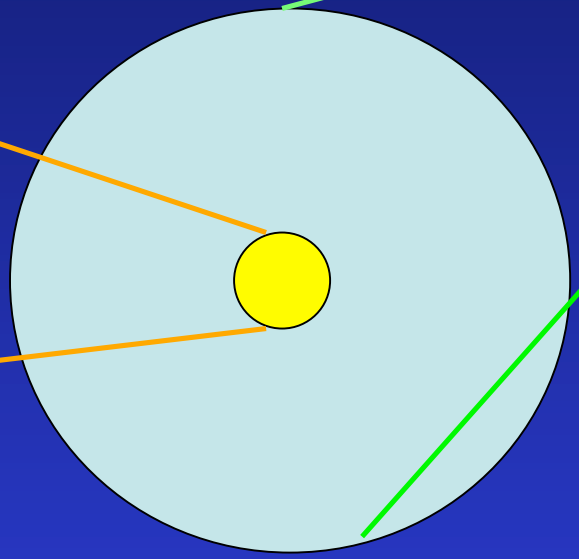
Iocco+ 08 $\sigma^{SD}_0=10^{-38}$ cm^2

Why should you care?

(surviving the ages)



Bertone & Merritt 05

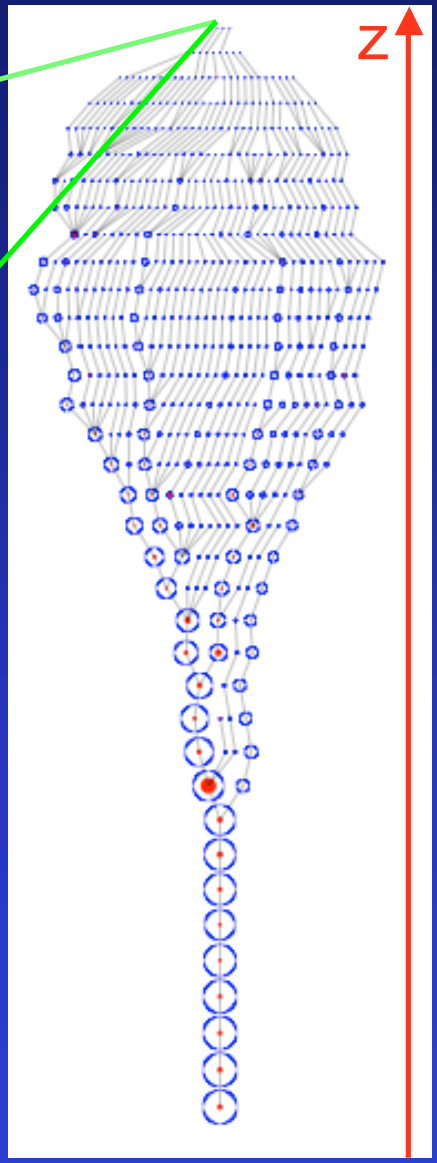


(not actual size)

Halo merger

DM cusp erosion

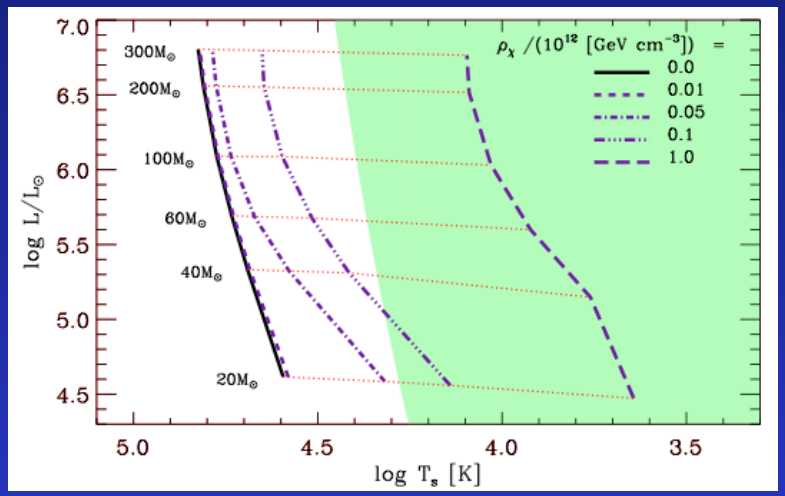
(baryons + self-annihilation)

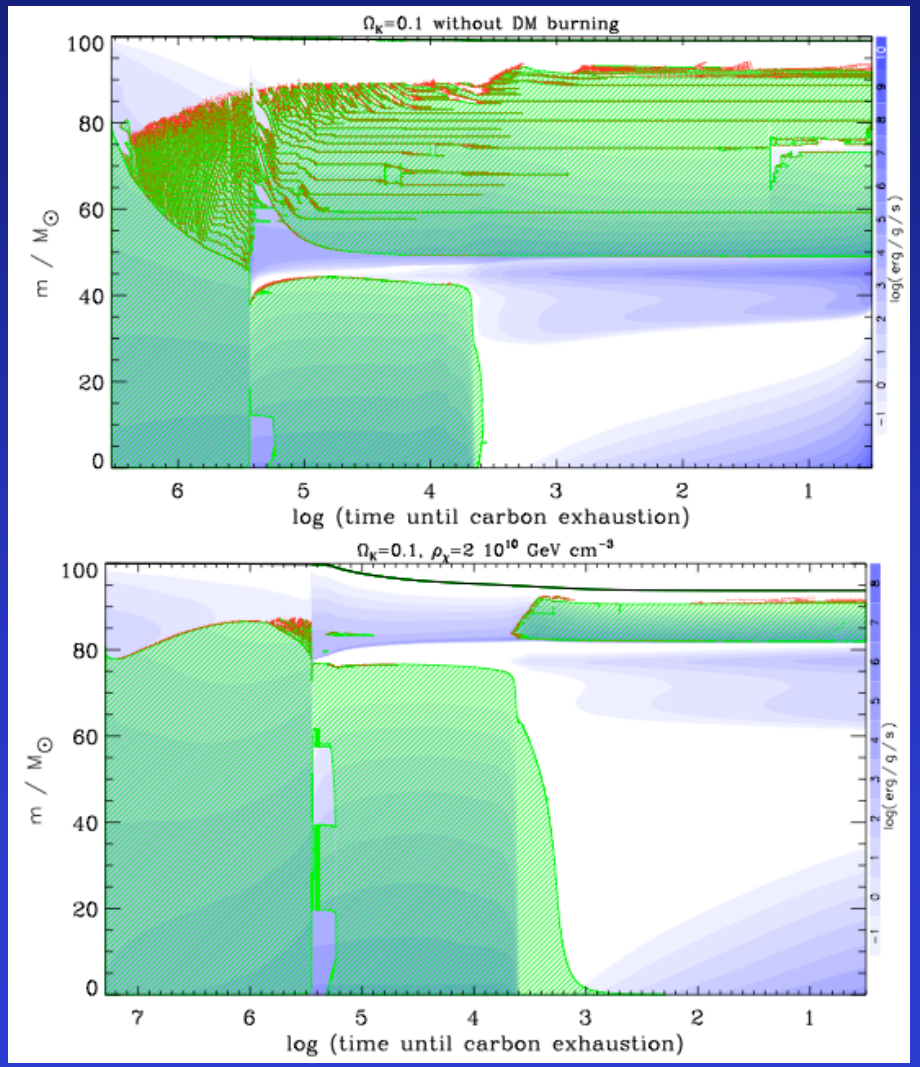


Wechsler + 02

Some more properties

(useful for indirect detection)





ionizing photons!

(tricky: increase or decrease depending on DM density)

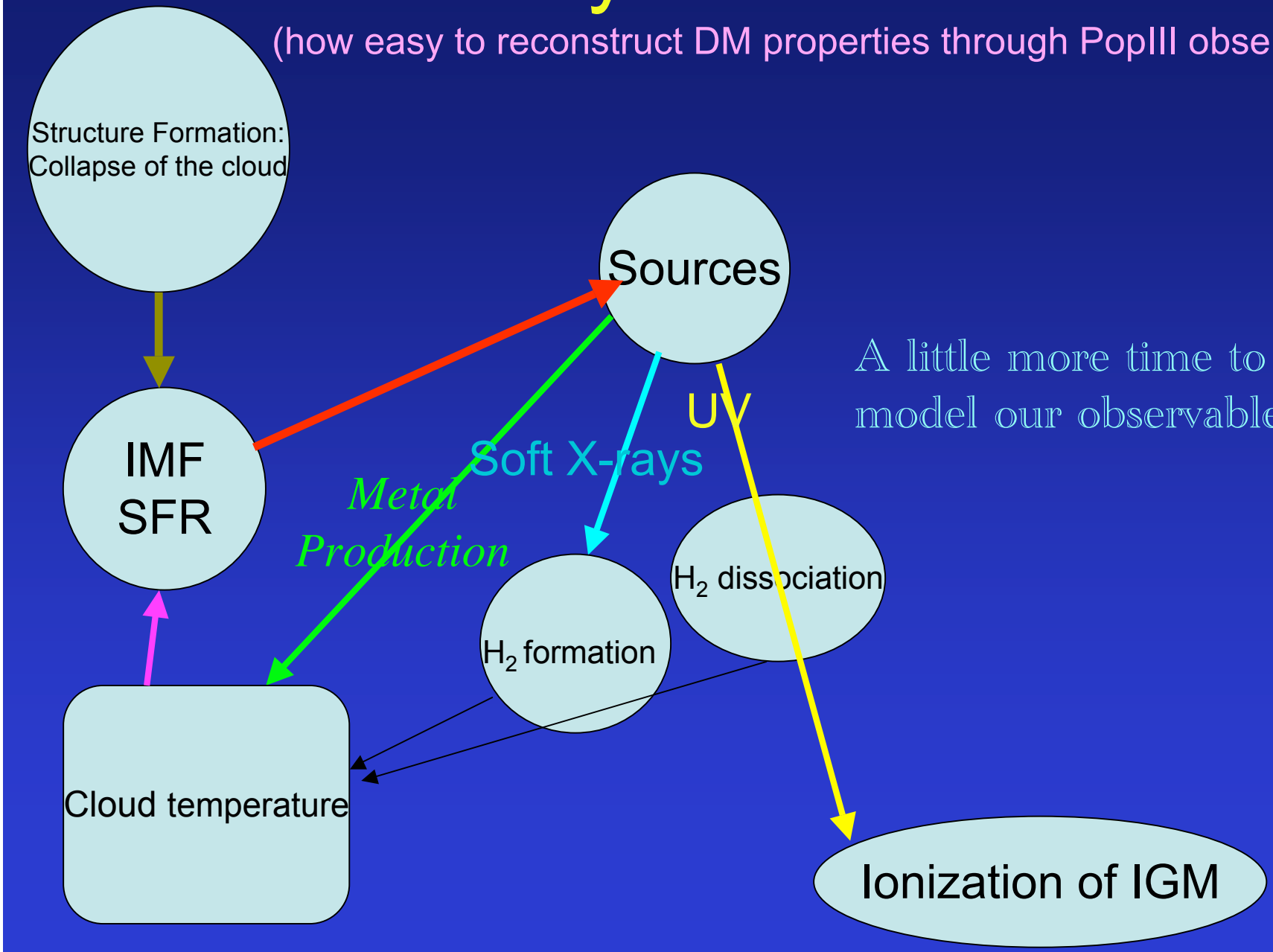
Chemistry

(yeah: analize that!)

Yoon, Iocco & Akiyama, ApJL 688, 2008

The Physics of Reionization

(how easy to reconstruct DM properties through PopIII observations)



A little more time to model our observables…

Concluding

In the early Universe:

TWO phases of DM annihilation in stars

AC stalling phase (Dark Star) is transient,
details yet to be understood

DM burning prolonges stellar lifetimes
(up to "freezing" the stars)

Which effects on local feedback and Reionization?

Need to understand their environment evolution