

Dark Stars

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International Centre for Theoretical Physics
South American Institute for Fundamental Research

*DM & stars workshop
Jussieu, Paris
June 6, 2016*

Dark Stars, what do you mean?

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Dark Stars, oh what a cool name

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Dark Stars, oh what a misleading name

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Dark Stars, flattening your semantics increases your ignorance

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Dark Matter and the First Stars: a complicated story (which deserves some more than two words)

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Effects of WIMP DM on the First Stars

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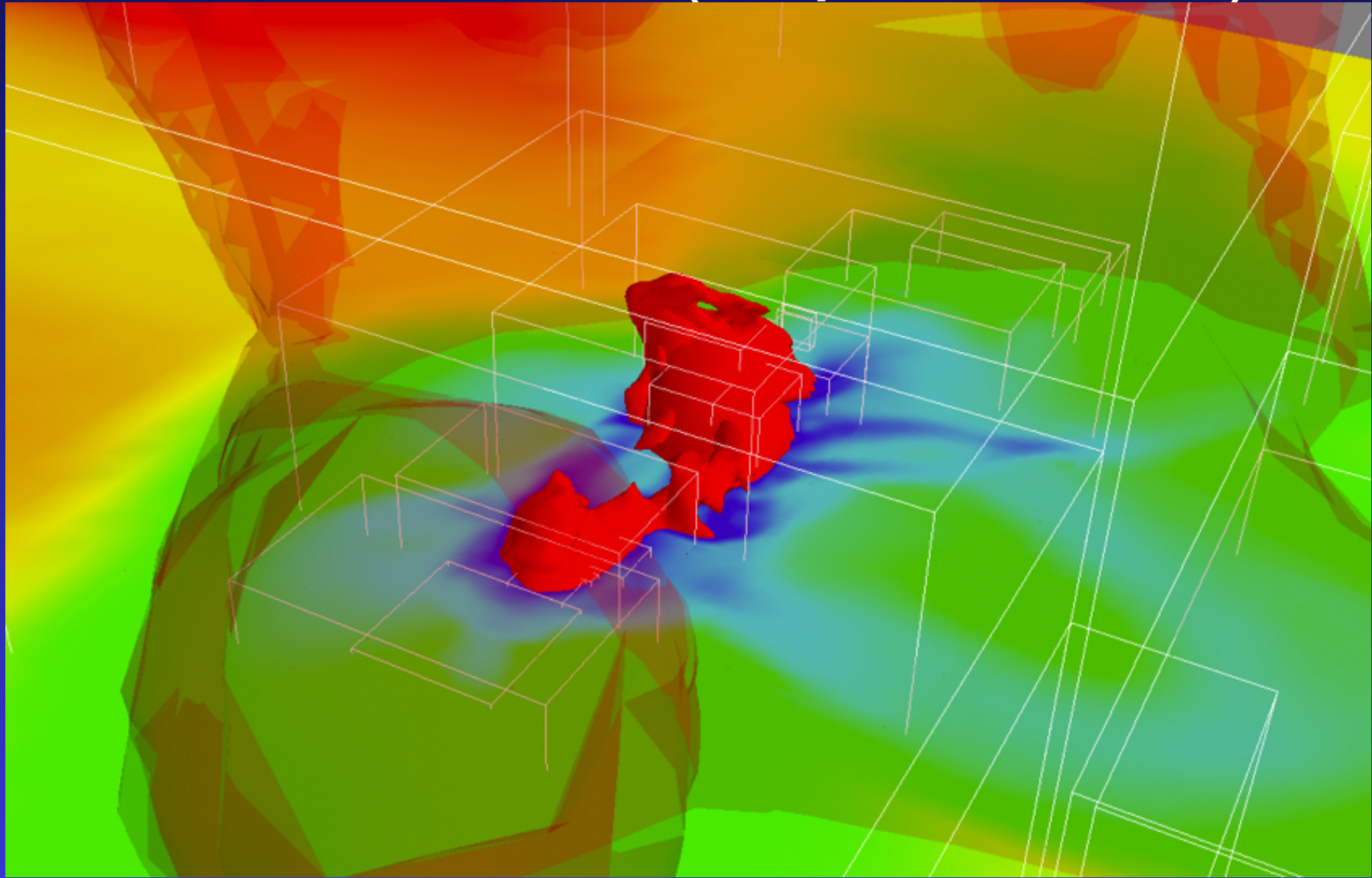
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Outline

- Population III stars: a very quick introduction
 - WIMP Dark Matter: two mechanisms for interacting with the bright world
- First Stars and WIMP Dark Matter : the physics and the observable effects
 - Proto-stellar phase and DM, which effects?
 - Does a “Dark Star” form? (Let’ s define a Dark Star)
 - Proto-stellar phase vs DM burning: a different phase
 - A new generation of stars? Observable signatures?

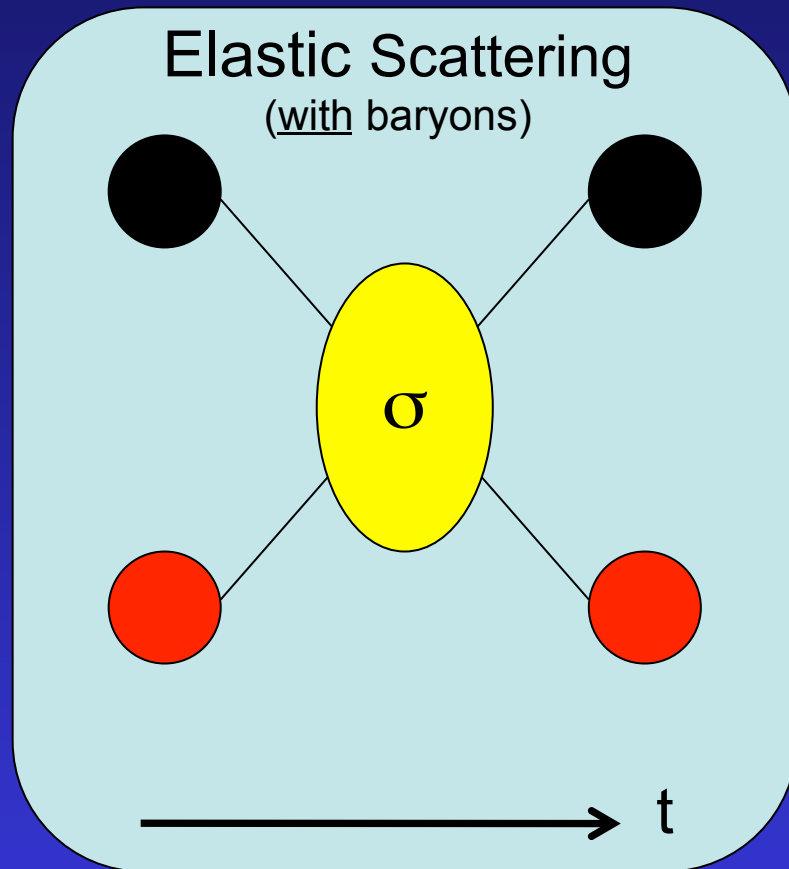
The first stars (Population III)



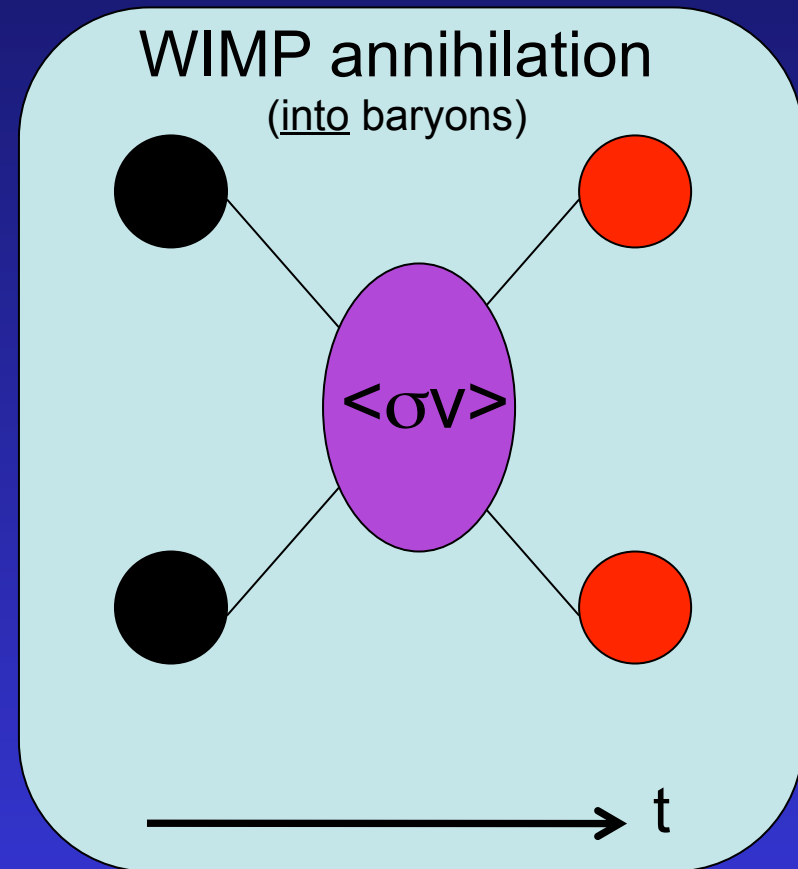
Simulations!

By courtesy of M. J. Turk

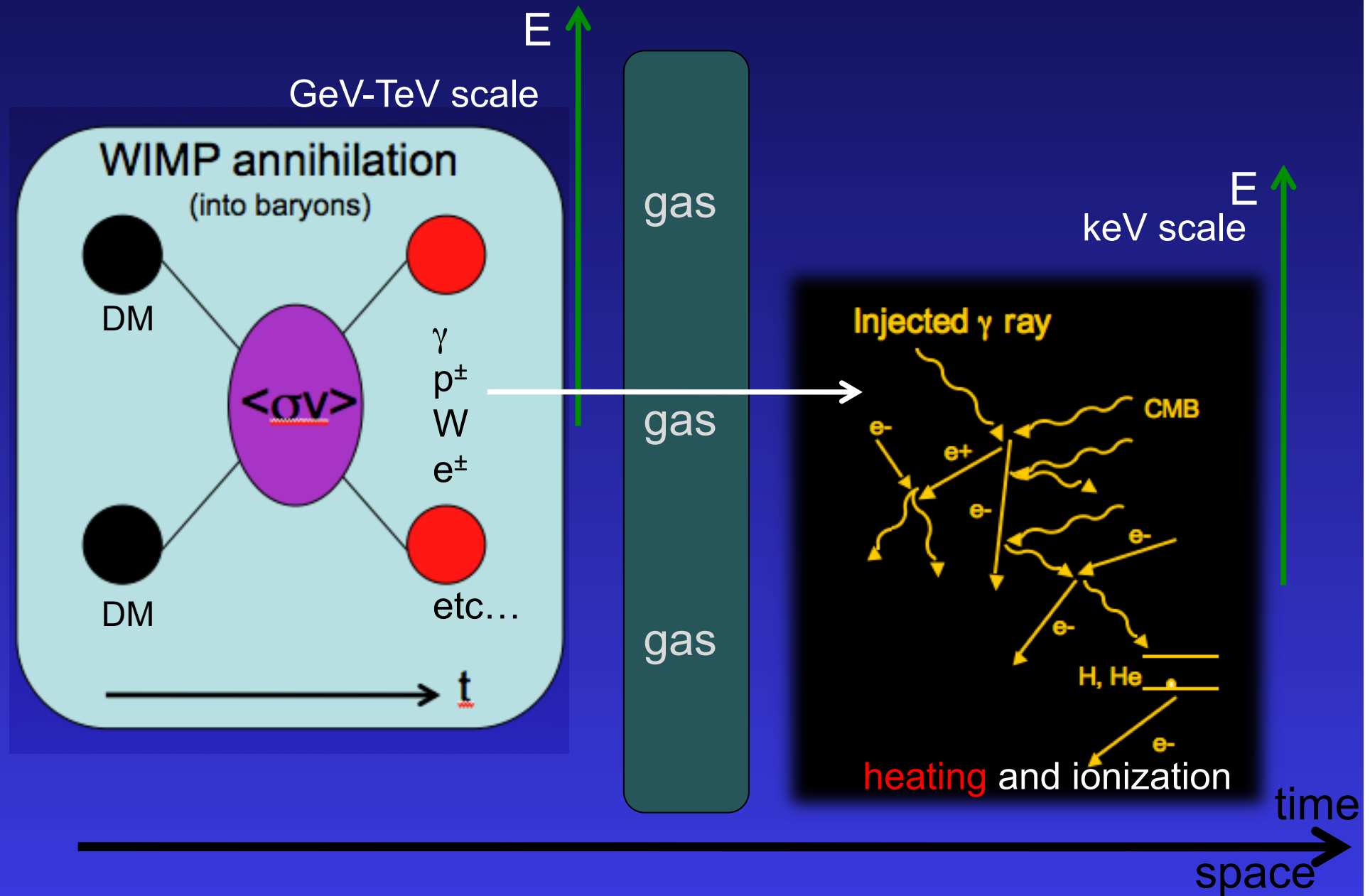
Two mechanisms of interaction



\neq



Effects of WIMP *annihilation* on gas



Dark Matter “Luminosity”

Energy injected by DM annihilation into the gas

$$L_{\chi}(r) \propto \frac{\langle \sigma v \rangle}{m_{\chi}} \rho_{\chi}^2(r) \times K_{gas}(r)$$

DM parameters:
(we trust them,
or we want to find them out?)

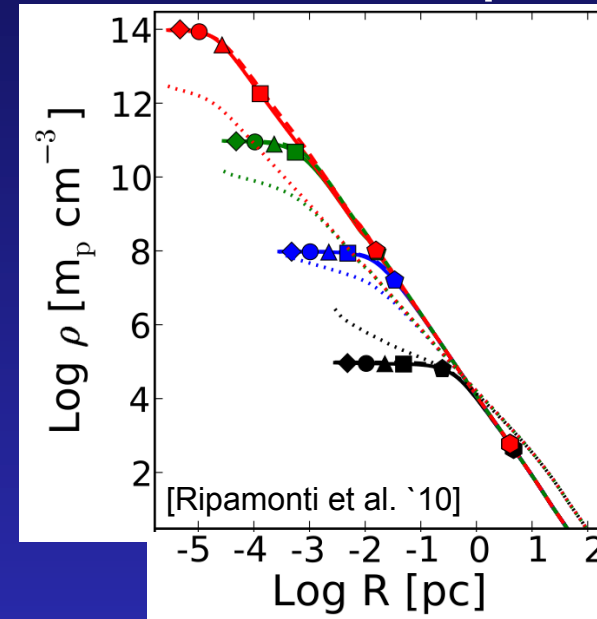
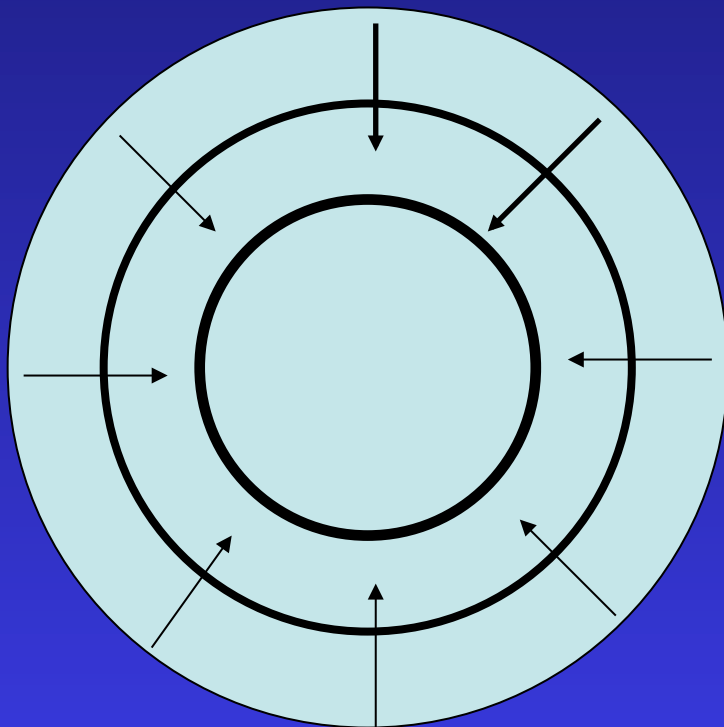
DM profile:
trust the simulations

Gas absorption profile:
don't trust anybody,
compute it

Gravitational Contraction

Gas collapse and build-up of the DM cusp

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



DM density up:
energy production

Gas density up:
higher opacity

$$L_{\chi}(r) \propto \frac{\langle \sigma v \rangle}{m_{\chi}} \rho_{\chi}^2(r) \times K_{gas}(r)$$

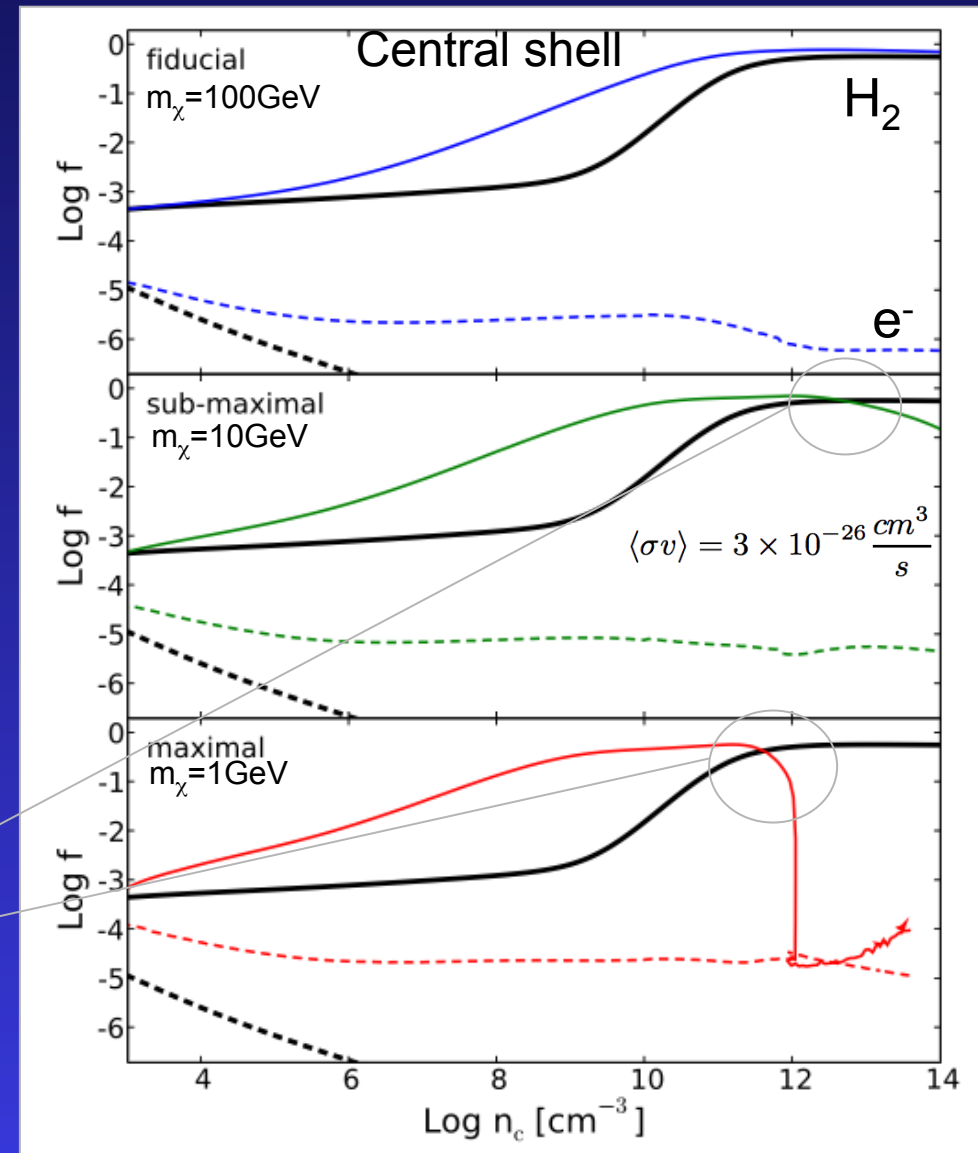
Feedback effects during protostellar phase

DM annihilations:

induces ionizations
ionizations catalyze H_2 formation

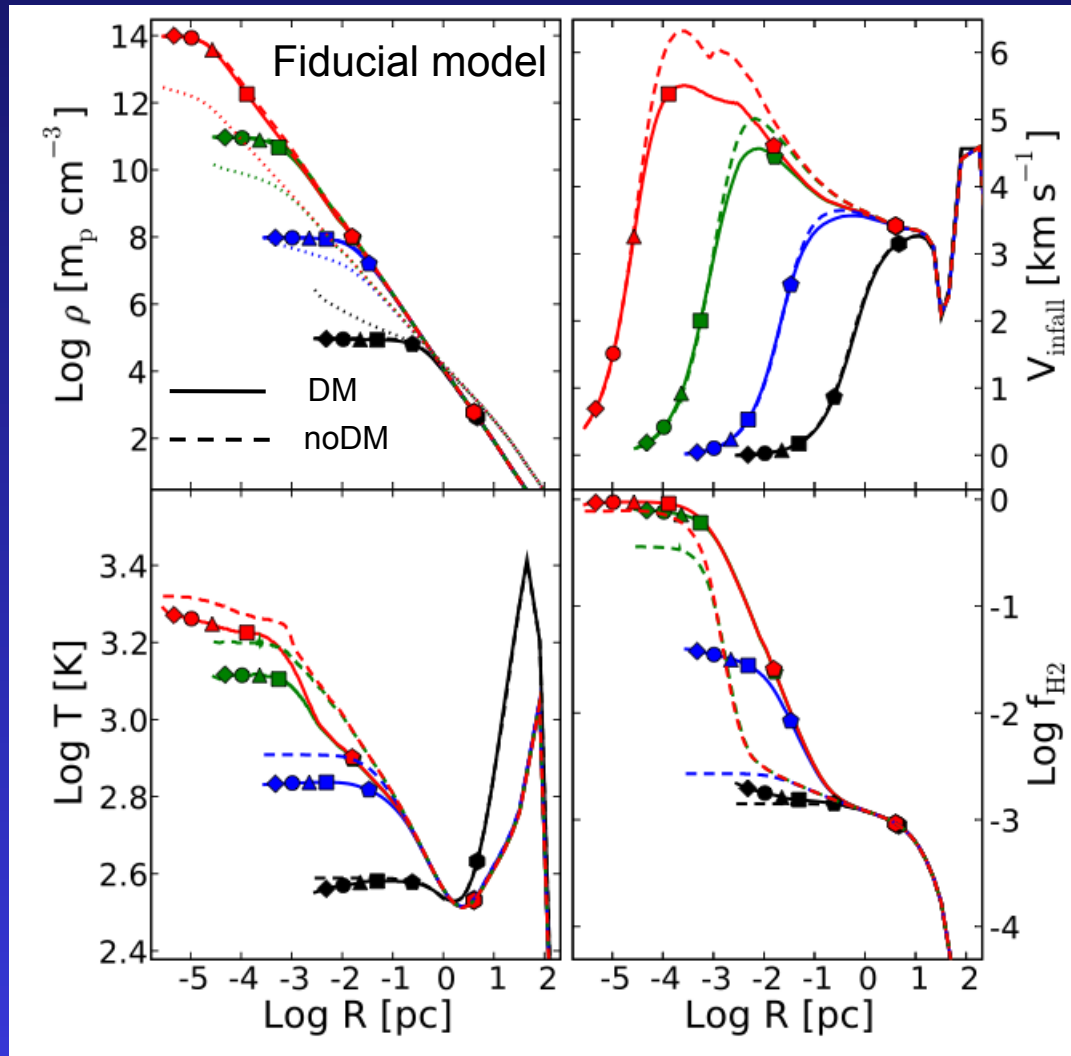
H_2 is a coolant: T down

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



[Ripamonti et al '09, '10]

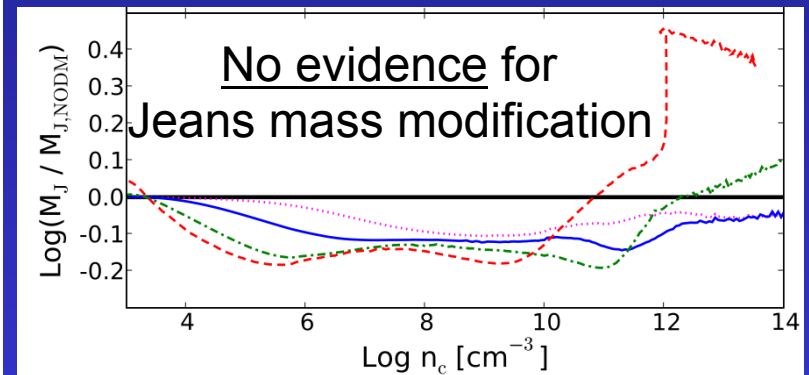
Feedback and *direct* DM effects (in proto-stellar phase)



no dramatic change in
(gas/DM) density structure

no dramatic change in
Temperature

no dramatic change in
infall velocity



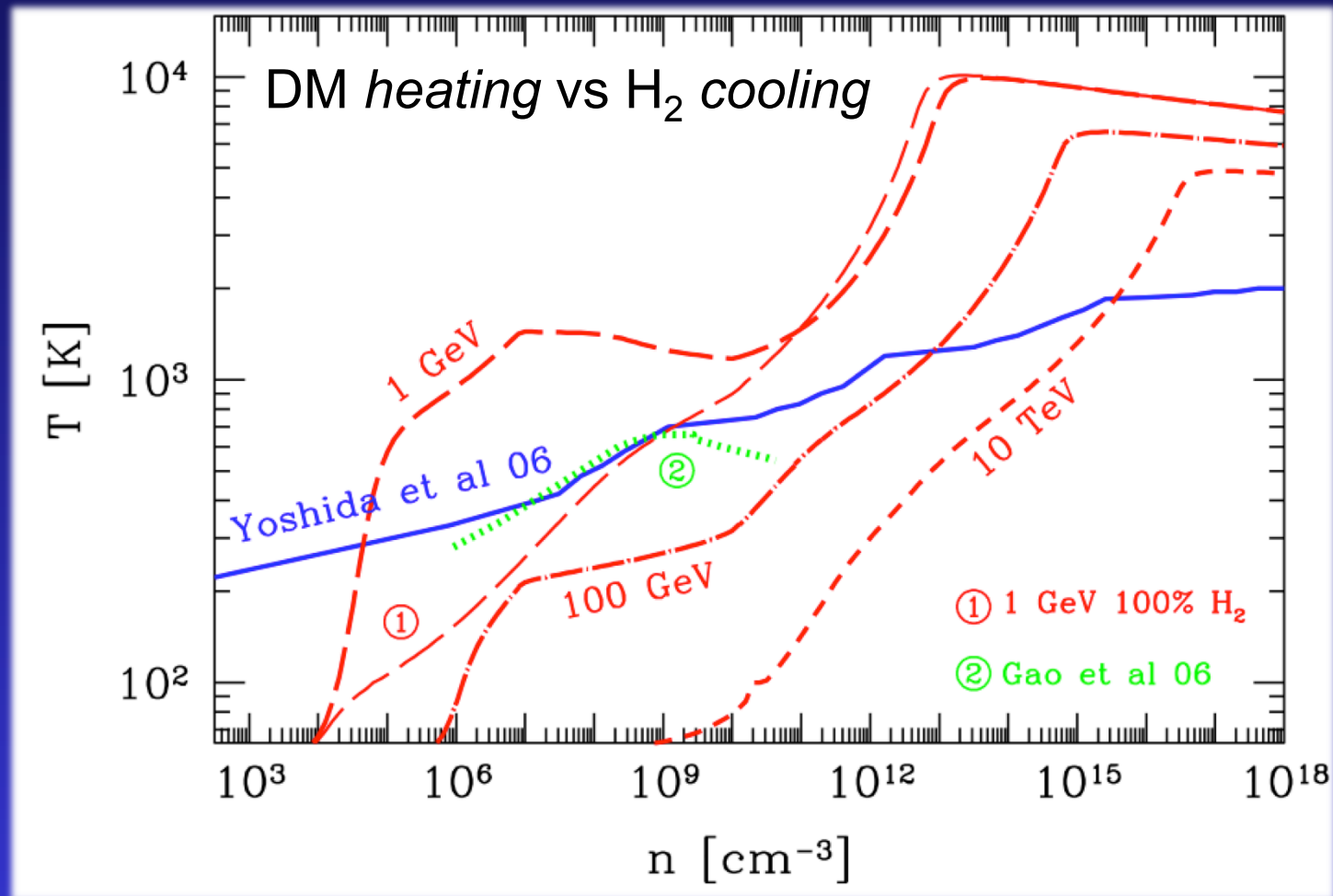
No evidence for
Jeans mass modification

[1D analysis]

[Ripamonti et al. '10]

See also 3D [Smith et al. '12]

Powering the structure (with DM)



[Spolyar, Freese, Gondolo '08] but original idea (uncited therein) from [Ascasibar, 2007]

At $n_{\text{gas}} \geq 10^{12} \text{ \#}/\text{cm}^3$
DM heating > H_2 cooling

The structure does not halt (no Dark Star “à la SFG”)

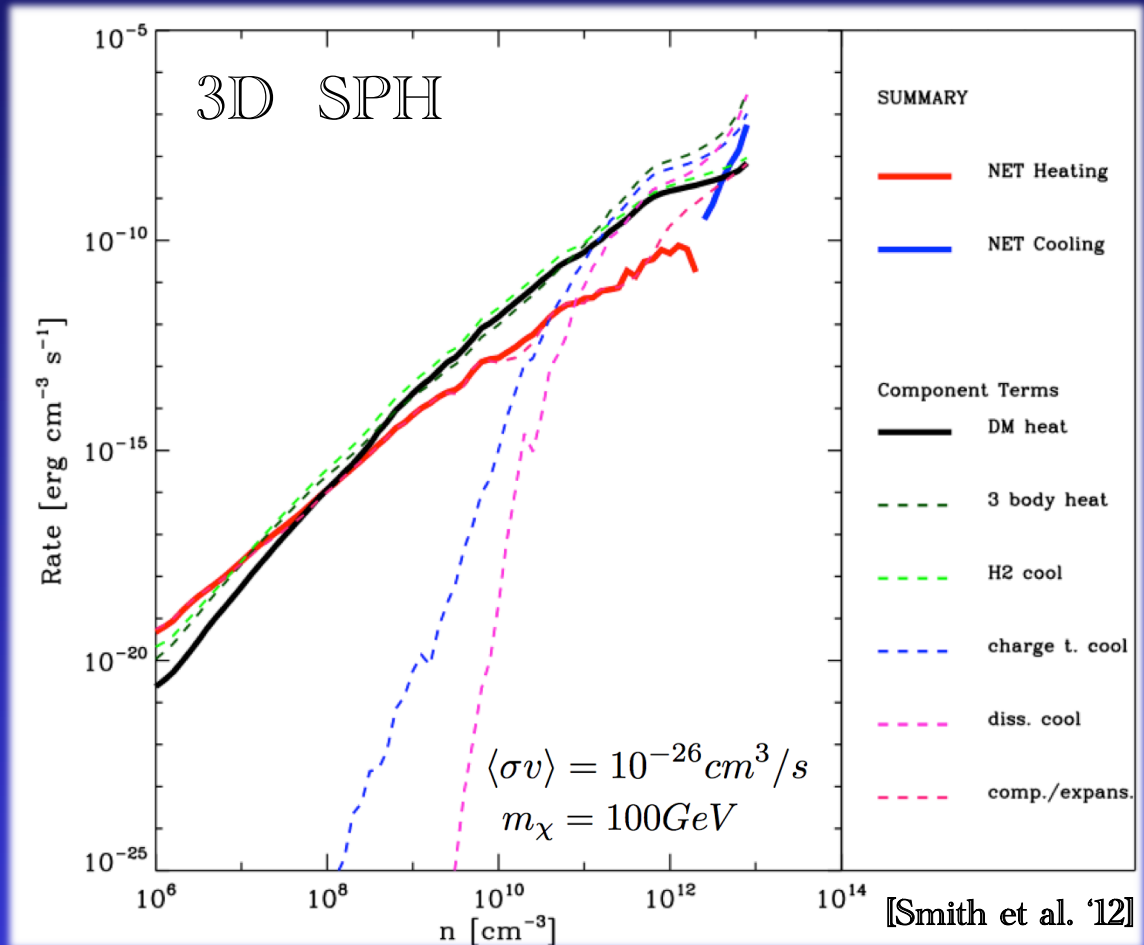
Just because now
H₂ cooling is not
the dominant coolant

3-body H₂ formation,
collisional dissociation,
charge transfer

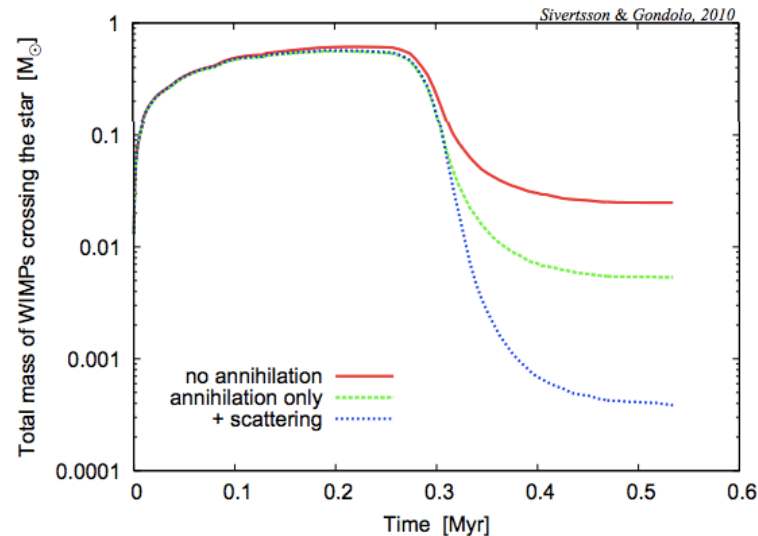
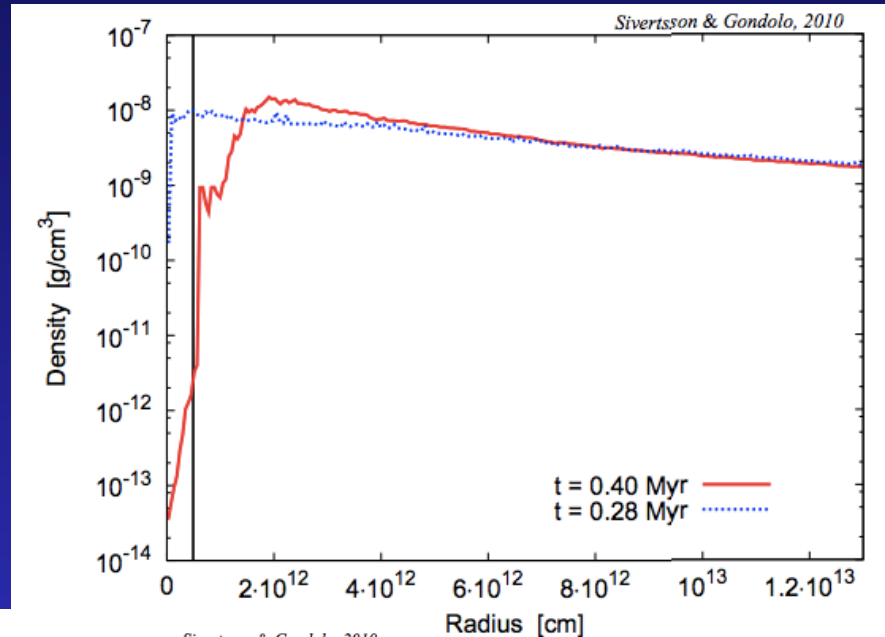
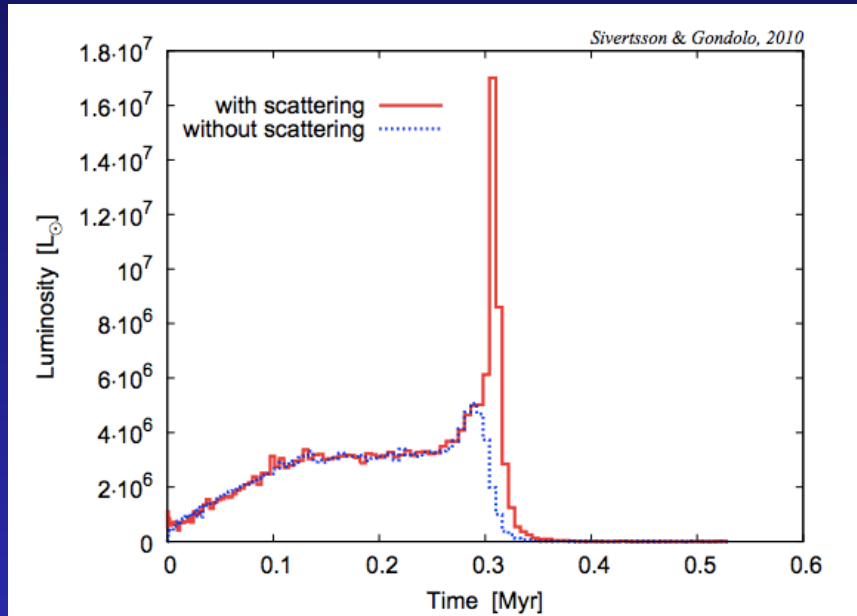
catch up as driving coolants:
formation of a
hydrostatic object

1D analysis of
[Ripamonti et al. '10]

3D analysis
(+higher densities) of
[Smith et al. '12]



The structure does not halt (studying a single object, self-consistently)



$$\sigma_{\text{ann}} v = 3 \times 10^{-26} \text{ cm}^3/\text{s}$$

$$m_{\chi} = 100 \text{ GeV}$$

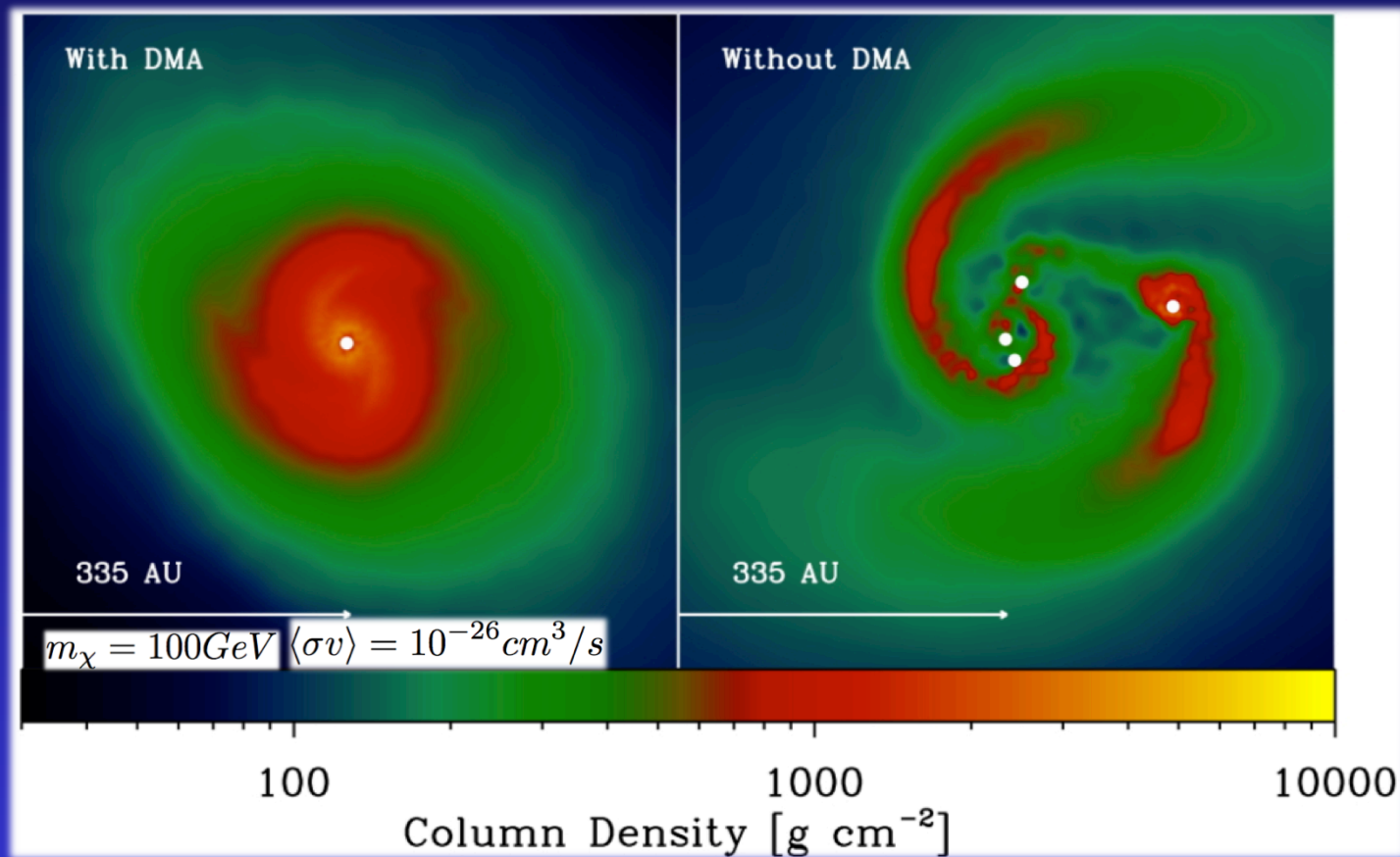
$$\sigma_{\text{scatt}} = 10^{-39} \text{ cm}^2$$

[Sivertsson & Gondolo, '10]

Here should be at least 5 slides on
all the literature (and criticisms to it)
predicting the formation of
supermassive or *hypermassive*
Population III stars which should
allegedly be possible according to
the SFG “dark star mechanism”

Since that is unphysical, I skip them

However: Fragmentation suppression

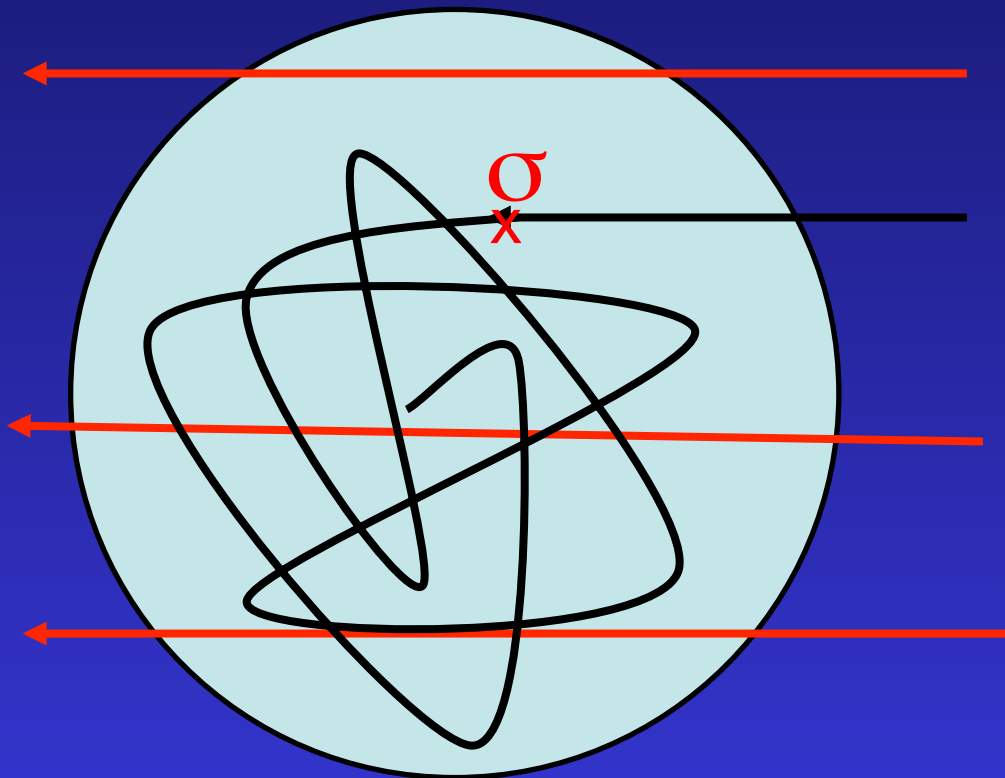


H_2 suppression \rightarrow Temperature rise

[Smith et al. '12]

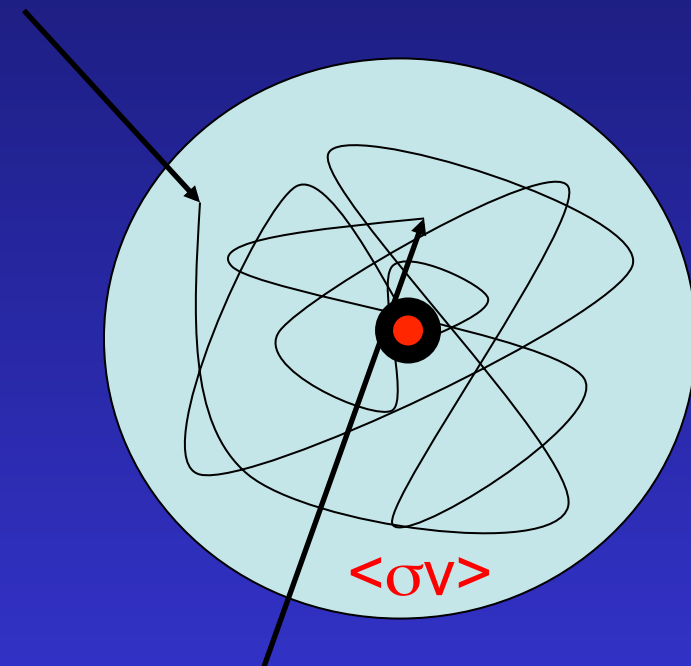
Scattering and Capture on a hydrostatic object

Halo WIMPs are captured



by scattering off the gas of the star

Captured WIMPs accumulate
inside the star, thermalize



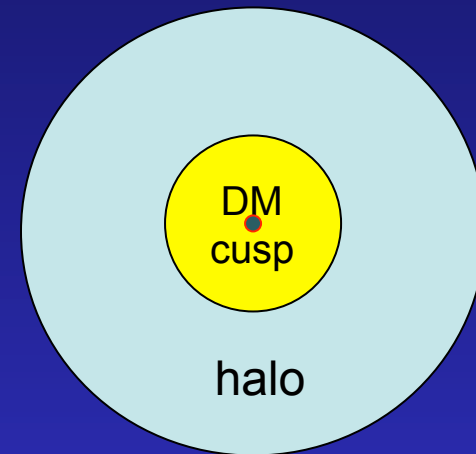
and “sink” to the center,
where they annihilate

[Iocco, 2008]

Eventually a star forms, (and it lives on the DM cusp)

Capture rate depends on *stellar* properties, and $\underline{\sigma}$ (bottleneck process)

$$C \propto \frac{\boxed{\sigma}}{m_{\chi}} \frac{\boxed{\rho}}{\bar{v}} \frac{M_{*}}{R_{*}}$$



And *environmental* ones
(continuously capturing halo WIMPs)!

Dark Matter annihilation from capture
inside first stars can overpower nuclear

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

Needs continuous replenishment!!!!

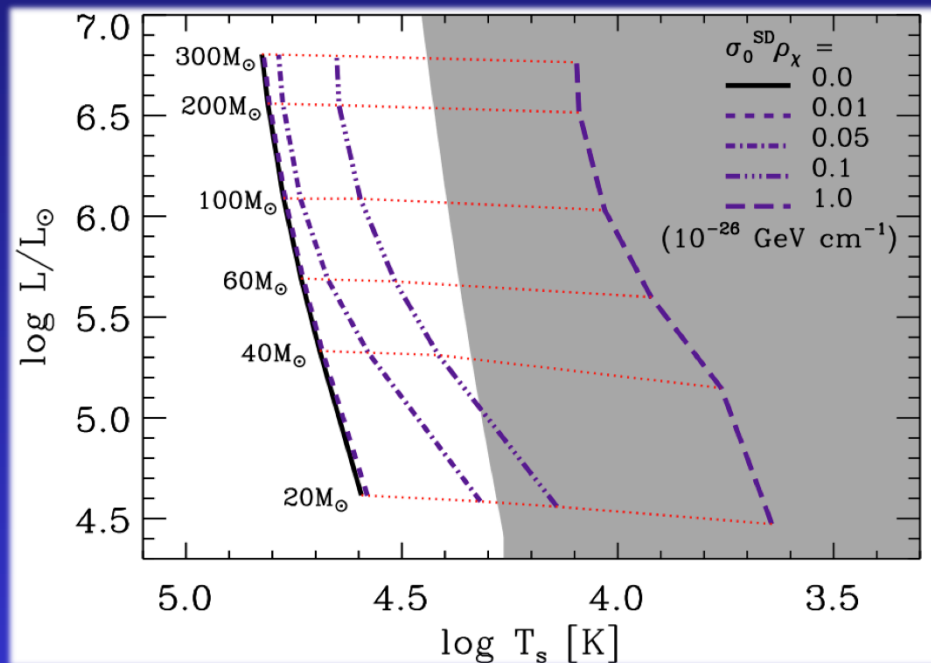
For PopIII, $L_{\text{DM}} \approx L_{*}$
quite naturally for not crazy parameters

[Iocco, 2008]

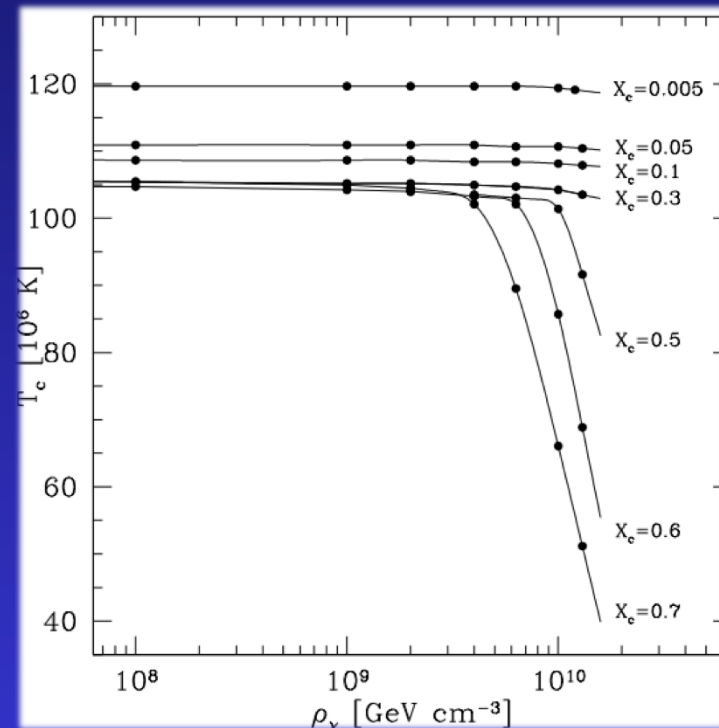
Scattering & Capture: main effects

STARS

EXPAND and cool down



[Iocco et al '08; Yoon, FI, Akiyama '08]



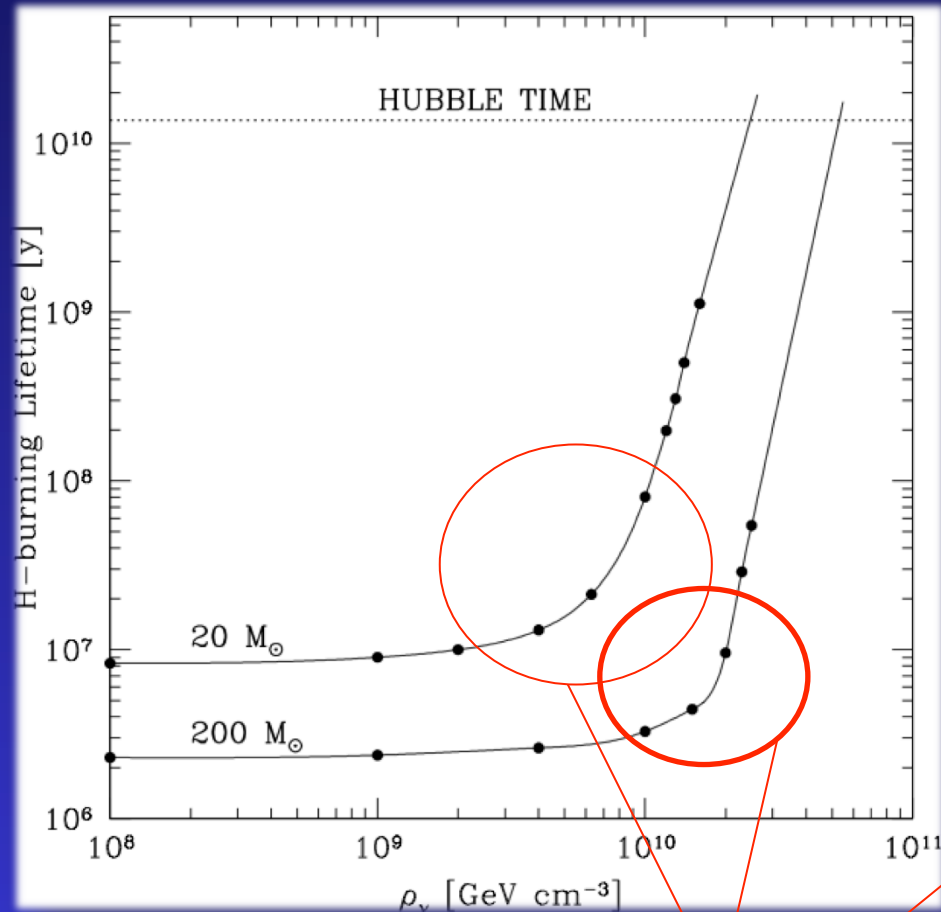
[Taoso et al. '08]

$$\sigma = 10^{-38} \text{ cm}^2$$

$$m_\chi = 100 \text{ GeV}$$

(the whole structure **cools down**, core included...)

Scattering & Capture (prolonging lifetimes)

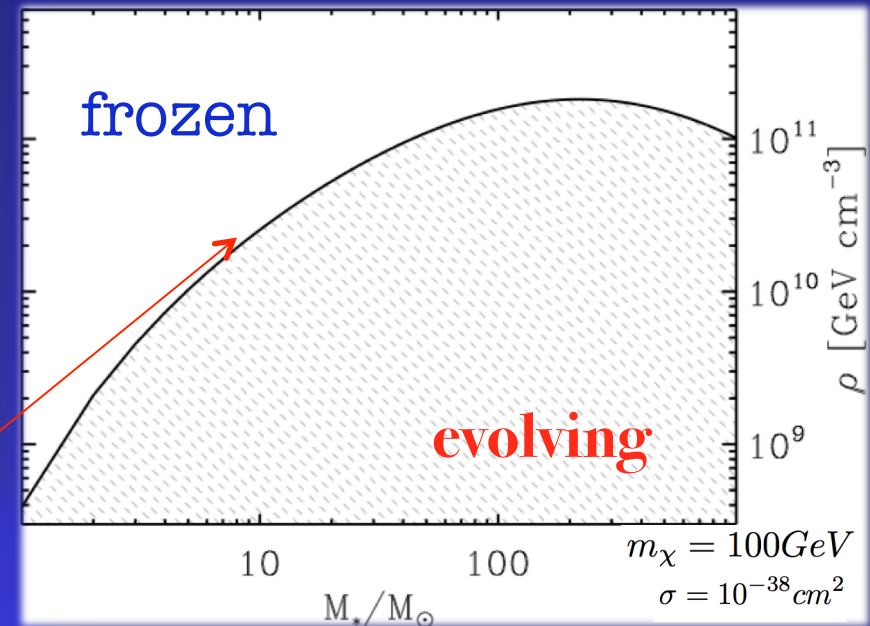


[Taoso et al. '08]

$\rho_{\text{crit}}(M)$

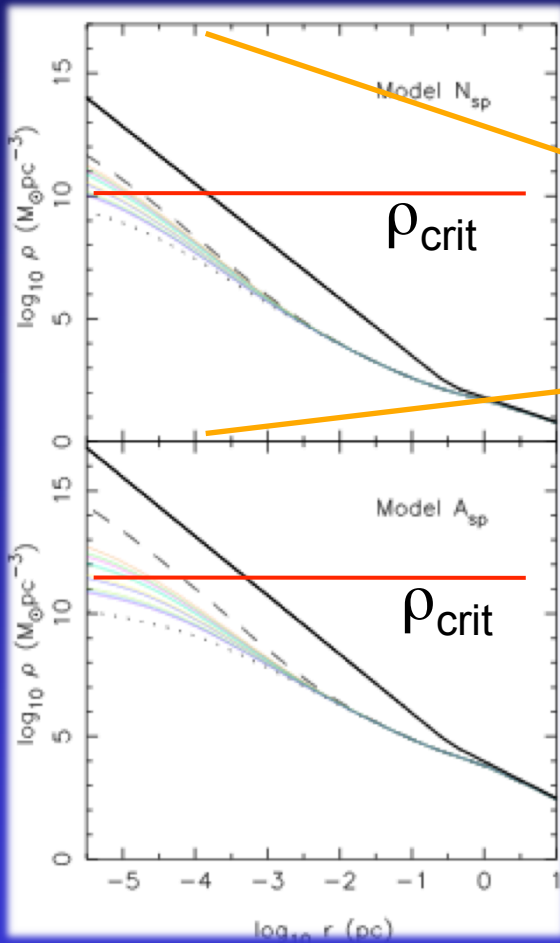
DM powered
stars are “frozen”

as long as environmental
DM stays supercritical

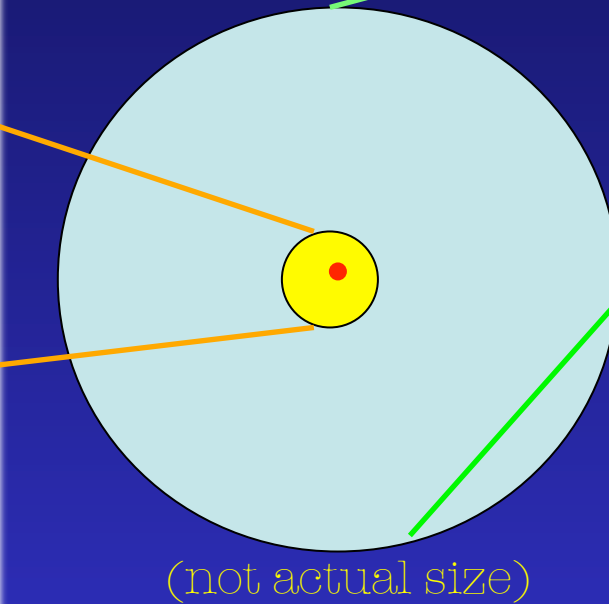


[Iocco et al. '08]

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

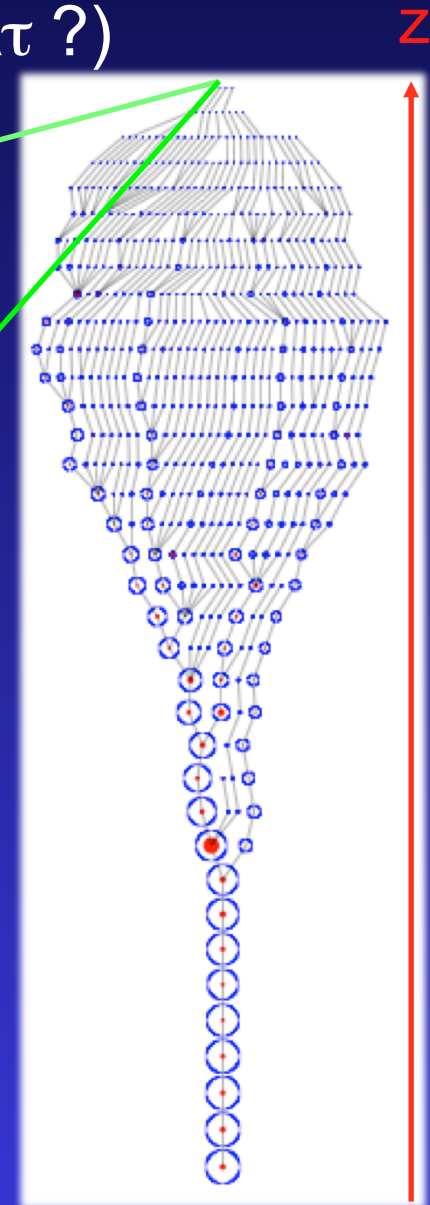


[Bertone & Merritt '05]



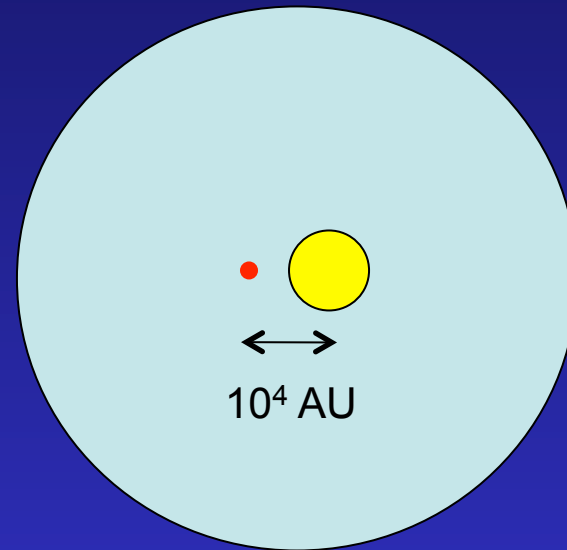
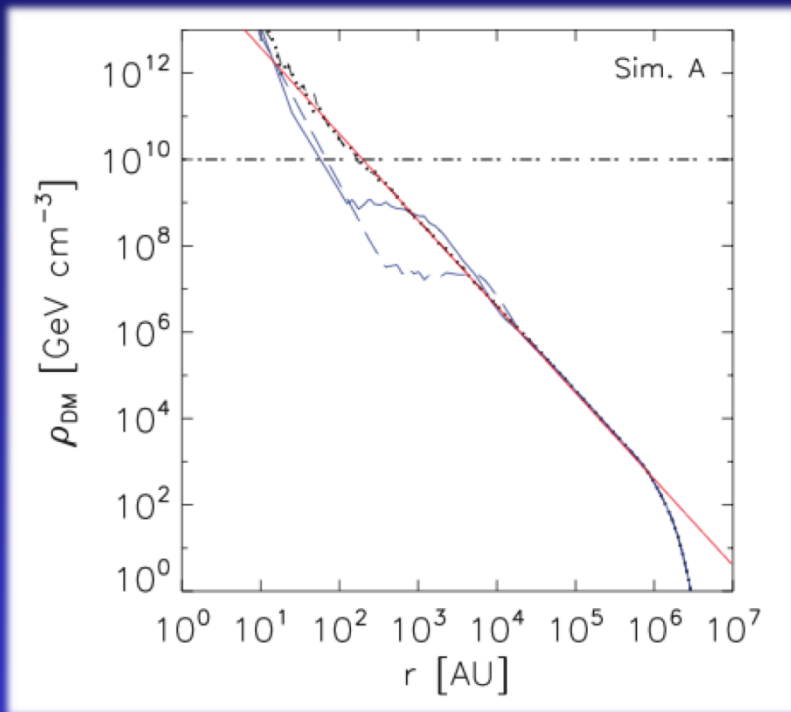
(not actual size)

Halo merger
DM cusp erosion
(*Baryons + self-annihilation*)



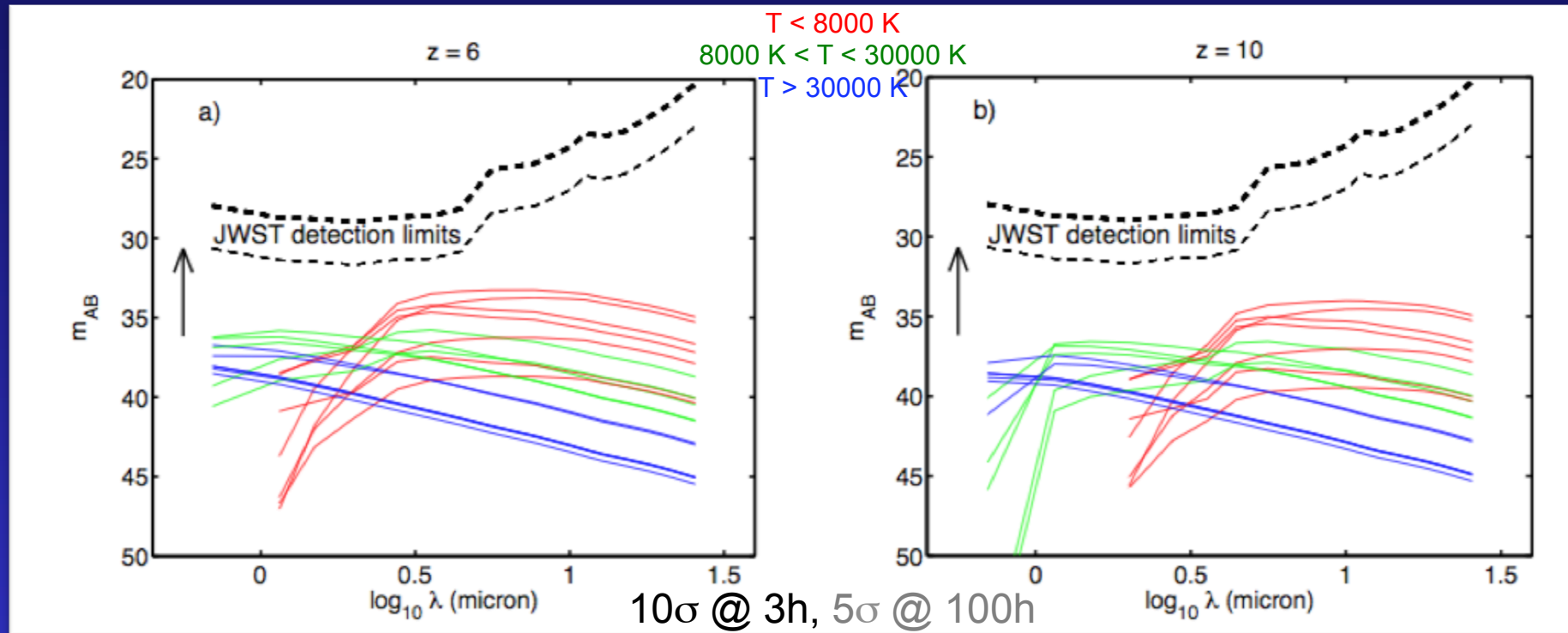
[Wechsler et al. '02]

Can such mechanism really affect a whole population?



Flattening of DM profile, disalignment between star and cusp center found in DM refined [10^{-2} - 10^{-5} Msun] simulations (proto-stellar phase not self-consistent)

Single DS Direct Observation? (with JWST)

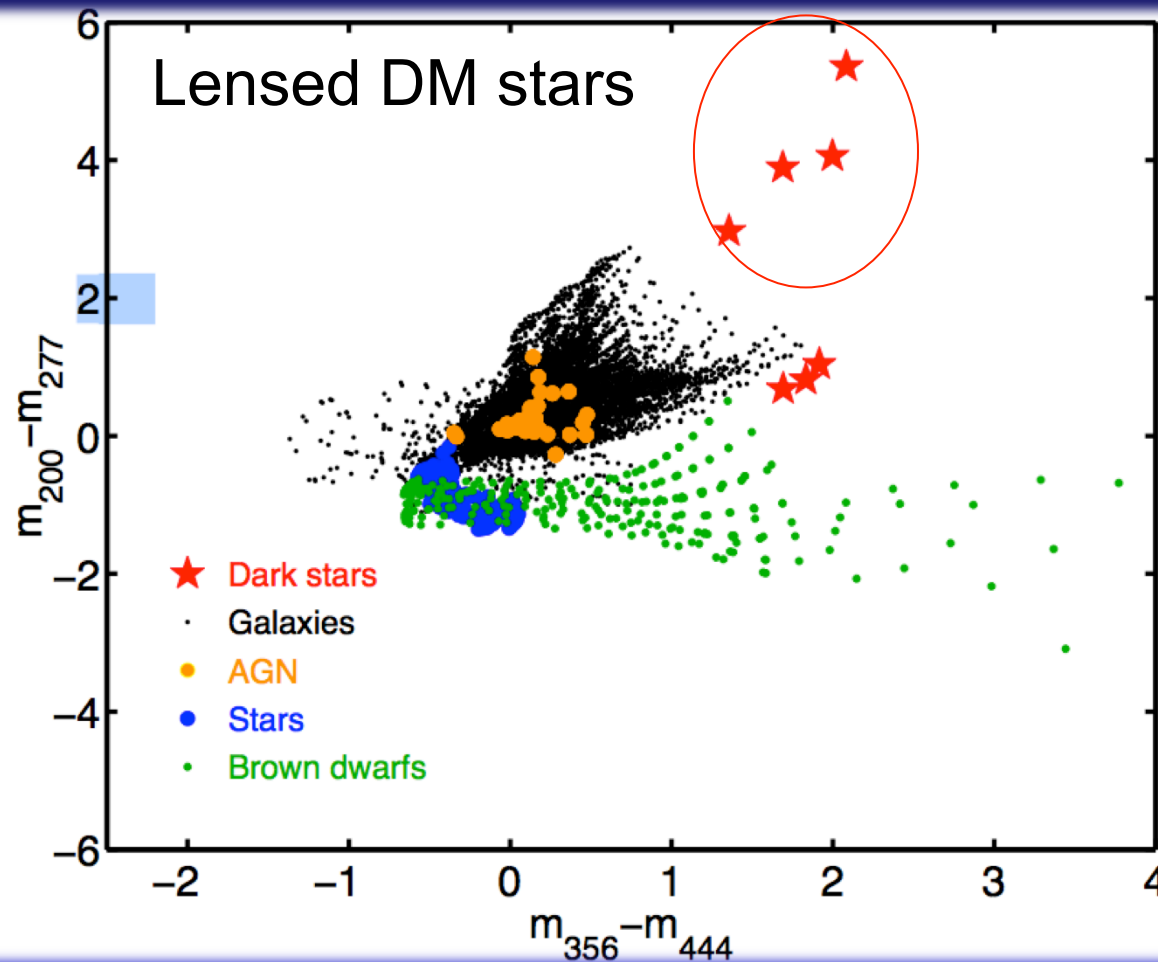


Real atmospheres vs Blackbody

$M_{DS} < 700$ solmass
Massive single DS are
intrinsically too faint
for JWST detection

[Zackrisson et al. '10]

Clustered and lensed DS observation and discrimination



Lens:

MACS J0717.5+3745

$M = 7.4 \times 10^{14} M_{\text{sun}}$ at $z = 0.55$

Color-color characteristics!

[Zackrisson et al. '10]

Conclusions

- Two phases, Gravitational vs Scattering DM “accretion”
- Gravitational accretion acts early
 - No dramatic indirect nor direct effect
 - No sensible Jeans mass modification
 - Evidence against super/hyper-massive star formation
 - Compelling hints of fragmentation suppression
- Capture by scattering (active around ZAMS)
 - Lifetime prolongement (MUST stay in proper DM bath, DM parameters)
 - Disalignement between hydrost. Obj. and DM cusp suppresses effects
- Observational possibilities (tough, but no “no go”) @ $z < 10$
 - Lensed, single objects
 - Clustered *capture* objects

Conclusion summary

- No Supermassive “Dark Star”
- Fragmentation Suppression during PopIII star formation
- Life prolongement possible (through scatter mechanism)

None of these mechanisms seems likely to affect dramatically the whole populaton

*“There are more things in heaven and earth ... ,
Than are dreamt of in your philosophy”*

[Shakespeare, \approx 1603]