The effects of dark matter annihilation upon the zero-metallicity ISM

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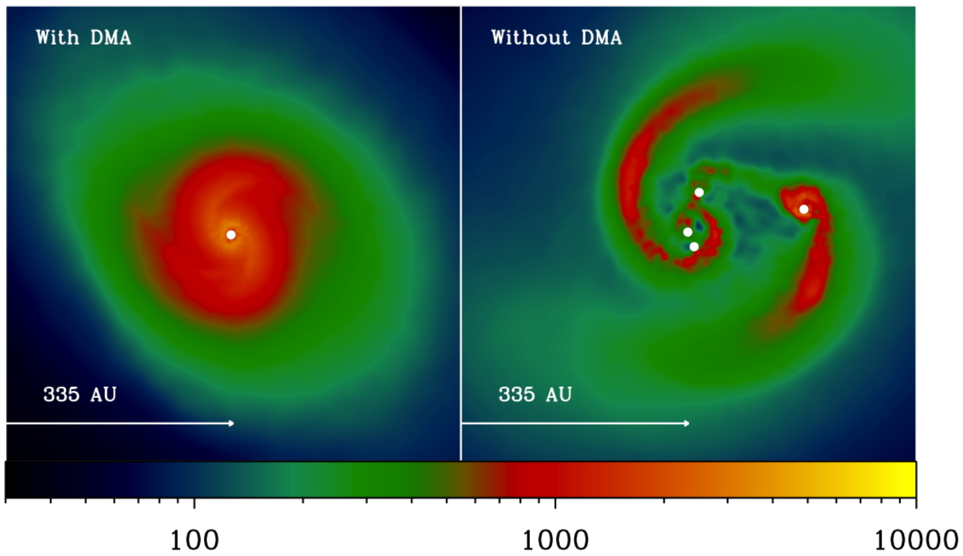

ARI ITA LSW

Abstract

1. Dark matter annihilation is insufficient to support the central regions of a halo against collapse, i.e. there are no darkstars.

2. Dark matter annihilation suppresses fragmentation in disks around the first stars.

Paper submitted to ApJ and available on the arXiv today.

Motivation

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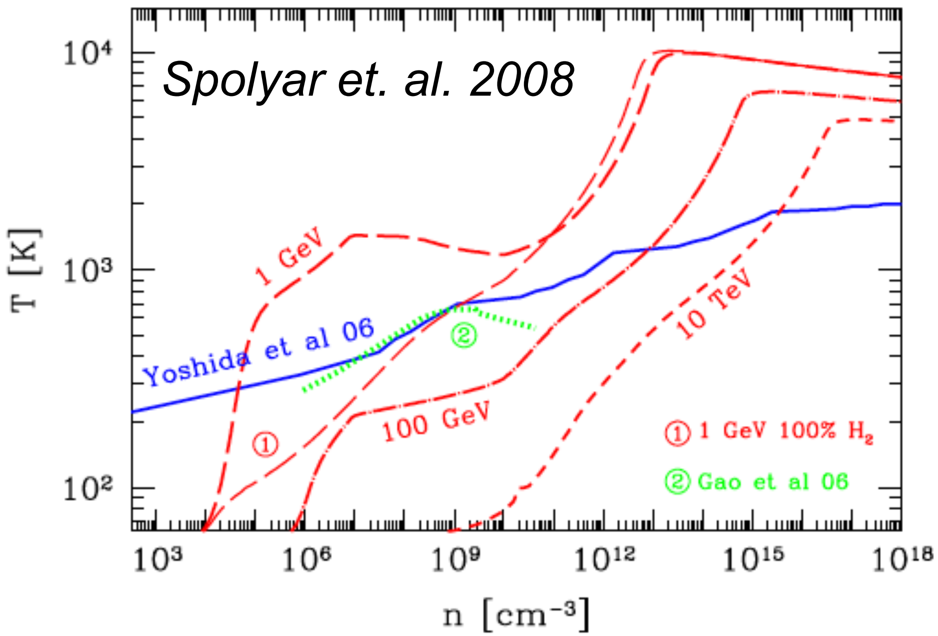
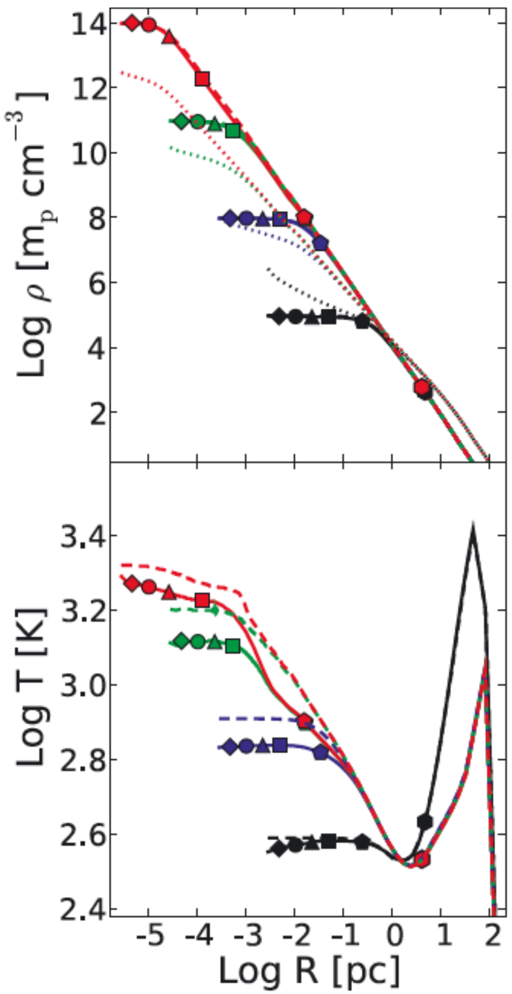
Dark Stars

Spolyar et. al. 2008 and Freese et. al. 2008 predicted DMA could support "Dark Stars"

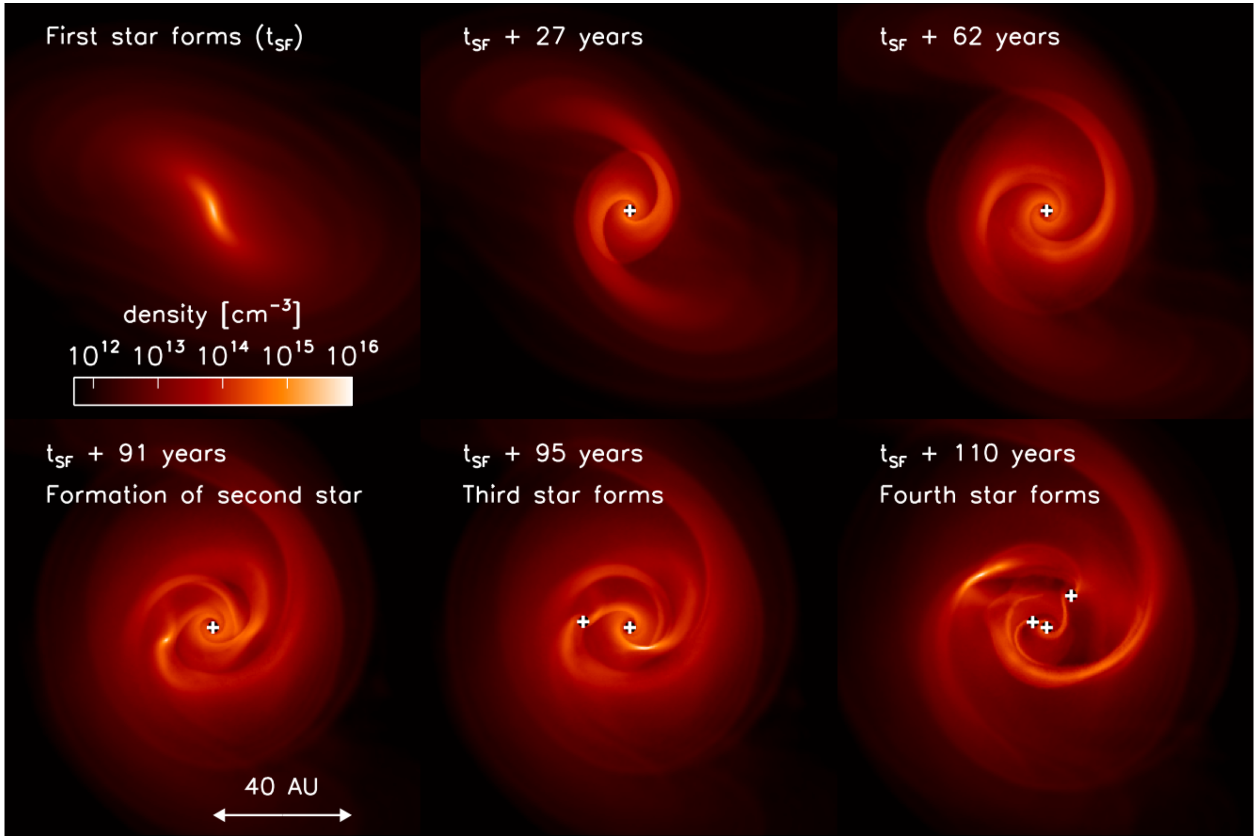
However this is in contradiction to the 1D simulations of Ripamonti et. al. 2010.





Ripamonti et. al. 2010

Fragmentation



Clark et. al. 2011b

Many authors have found primoridial protostellar disks to be unstable.

eg Stacy et. al. 2010, Clark et. al 2011, Greif et. al. 2011, Smith et. al. 2011

The Simulation

2

The Simulation

As in previous works:

- Gadget 2 *(Springel et. al. 2005)*
- Time dependent chemical network *(Glover & Abel 2008, Clark et. al. 2011a)*
- Accretion luminosity heating *(Smith et. al. 2011)*
- Cosmological initial conditions *(Greif et. al. 2011)*

Dark Matter

Included the effects of dark matter annihilation (DMA) from a dark matter density profile ρ_x of the form

$$\rho_x = N_0(r/1\mathrm{pc})^{-1.8}$$

outside the dark matter core R_c, and

$$\rho_x = \rho_{xc}(r/R_c)^{-0.5}$$

inside the core.

The core of the dark matter (DM) profile decreased in radius and increased in density as the baryons collapsed, following the relationship found in *Spolyar et. al. 2008.*

$$\rho_{xc} \approx 5GeV/\mathrm{cm}^{-3}(n/\mathrm{cm}^3)^{0.81}$$

DMA induced Chemistry

We assume

- dark matter particle cross section of $<\sigma v>=3\times10^{-26}$ cm^{3}s^{-1}
- gas opacity of $\kappa=0.01$ cm^{2}g^{-1} to annihilation products
- super-symmetric dark matter particle mass of 100 GeV

We assume a third of the DM energy escapes via neutrinos and the remainder is split between heating and ionisation components (*Valdes & Ferrara 2008*)

$$f_h = 1 - 0.875(1 - x_{\mathrm{e}}^{0.4052})$$

$$f_i = 0.384(1 - x_{\mathrm{e}}^{0.542})^{1.1952}$$

DMA induced Chemistry

The extra heating Q_h from annihilation is directly added to our time dependent chemical network *(Clark et. al. 2011a).*

Ionisation changes the relative abundances of the species by ionising H, He, He^+ and D, and dissociating of H_2,HD and H_2^+ (*Ripamonti et al. 2007*).

DMA can affect the temperatures in two ways
Positive: direct heating of the gas and destruction of H_2 at high densities.
Negative: an increased amount of H_2 at low densities due to the greater abundance of free electrons.

Initial Collapse

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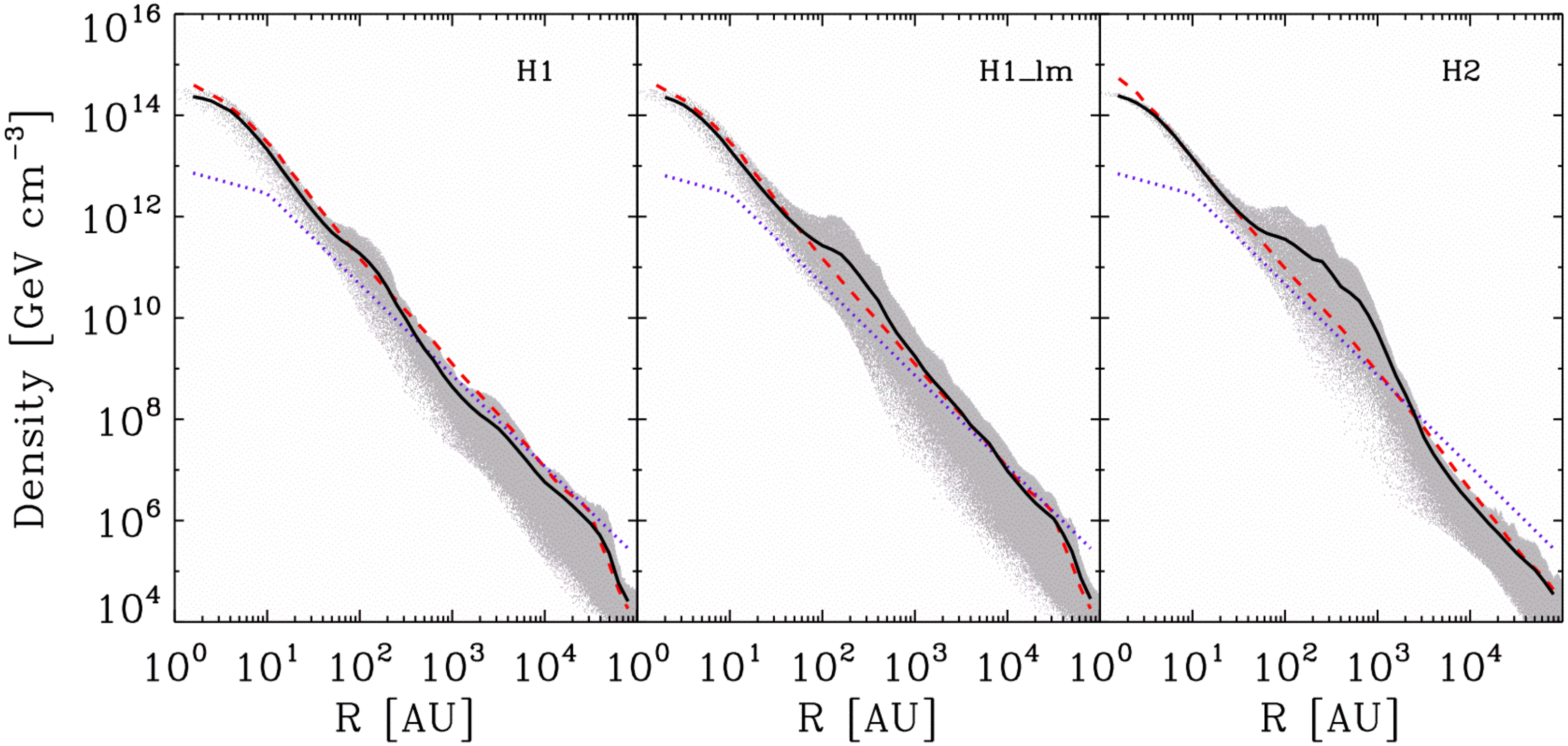
Density

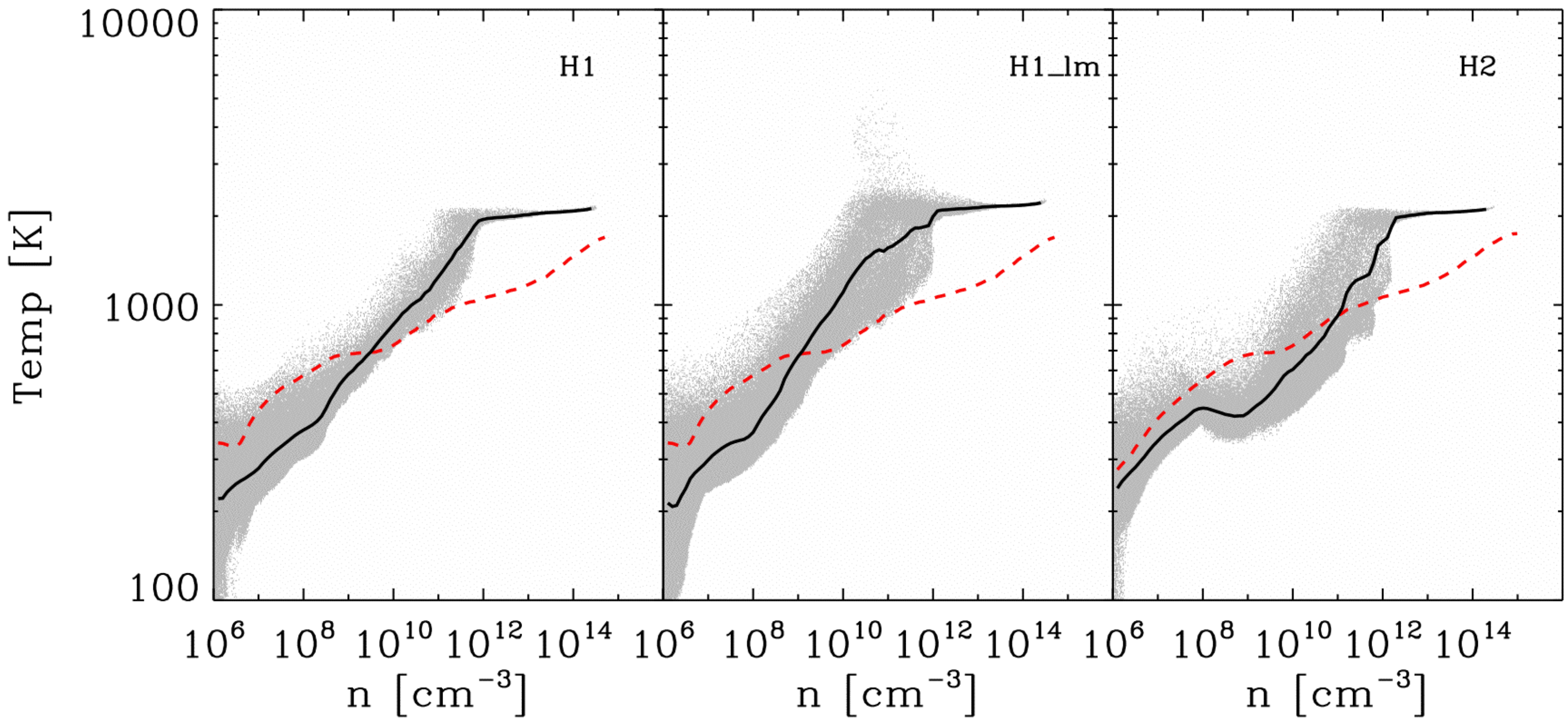


Gas still collapses to high densities.

Density enhancement between 100-1000 AU.

For dark stars it is predicted initial collapse stops at 10 AU.

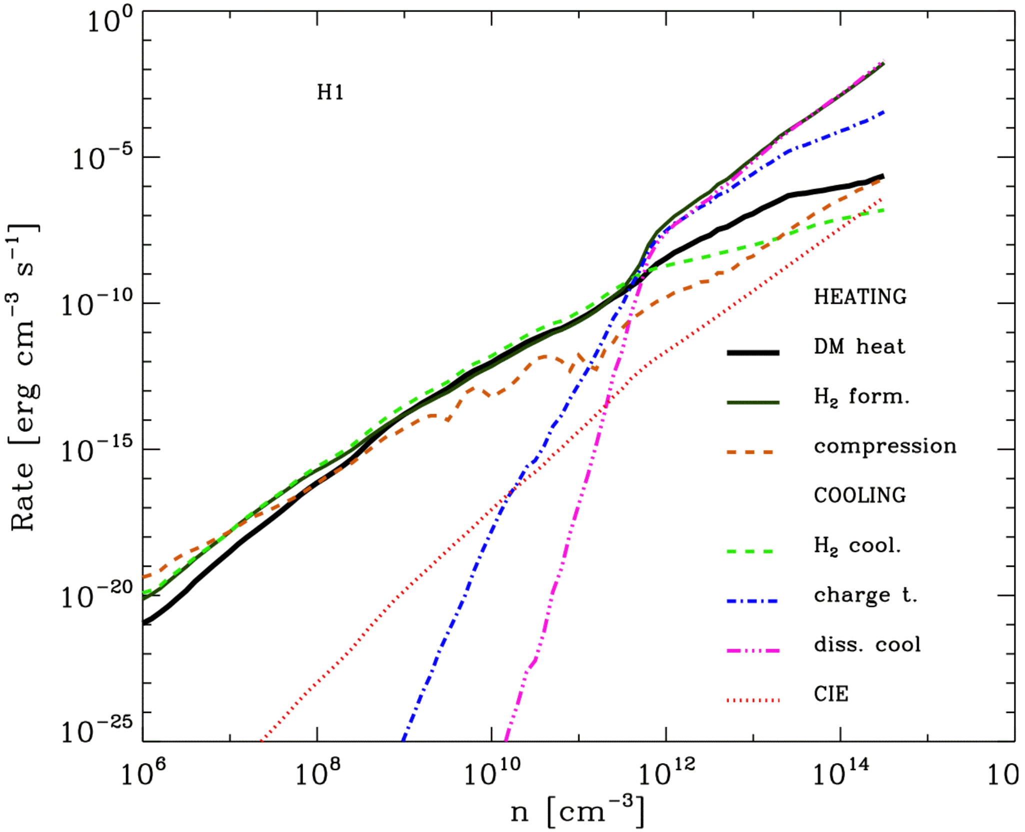
Temperature

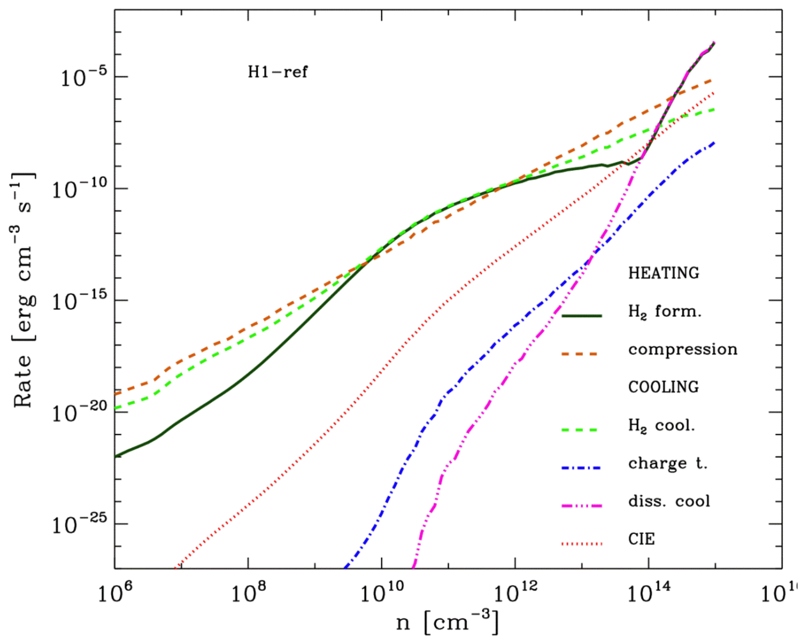


Temperature higher in the inner regions.

But, it does not rise much above 2000 K.

Chemical Rates





H_2 dissociation

Energy to dissociate H_2

$$E_{\mathrm{H_2}} = 4.48\mathrm{eV} \times x_{\mathrm{H_2}} n,$$
$$\simeq 1400 \left(\frac{n}{5 \times 10^{14}\ \mathrm{cm^{-3}}} \right) \mathrm{erg\ cm^{-3}},$$

At $n = 5\times10^{14}$ cm^{-3}, $x_{H2} \sim 0.4$ and the DMA heating rate $\Gamma = 5\times10^{-6}$ erg s^{-1}cm^{-3}

$t_{dis} = 1400 / 5\times10^{-6} \sim 3\times10^{8}$ s ~ **10 yr**

t_{ff} ~ **2 yr**

Free fall time is faster than the time needed to dissociate H_2 and raise the gas temperature above 2000 K.

Secondary Fragmentation

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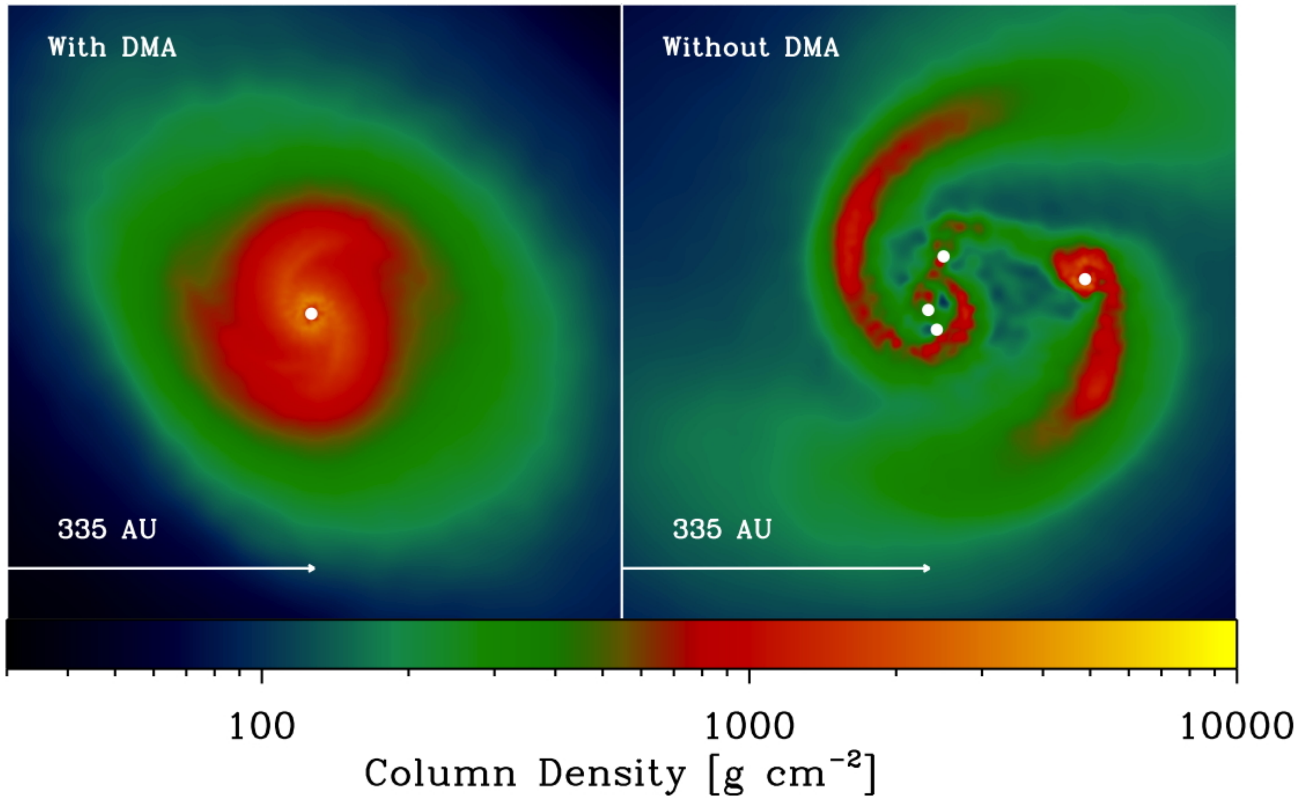
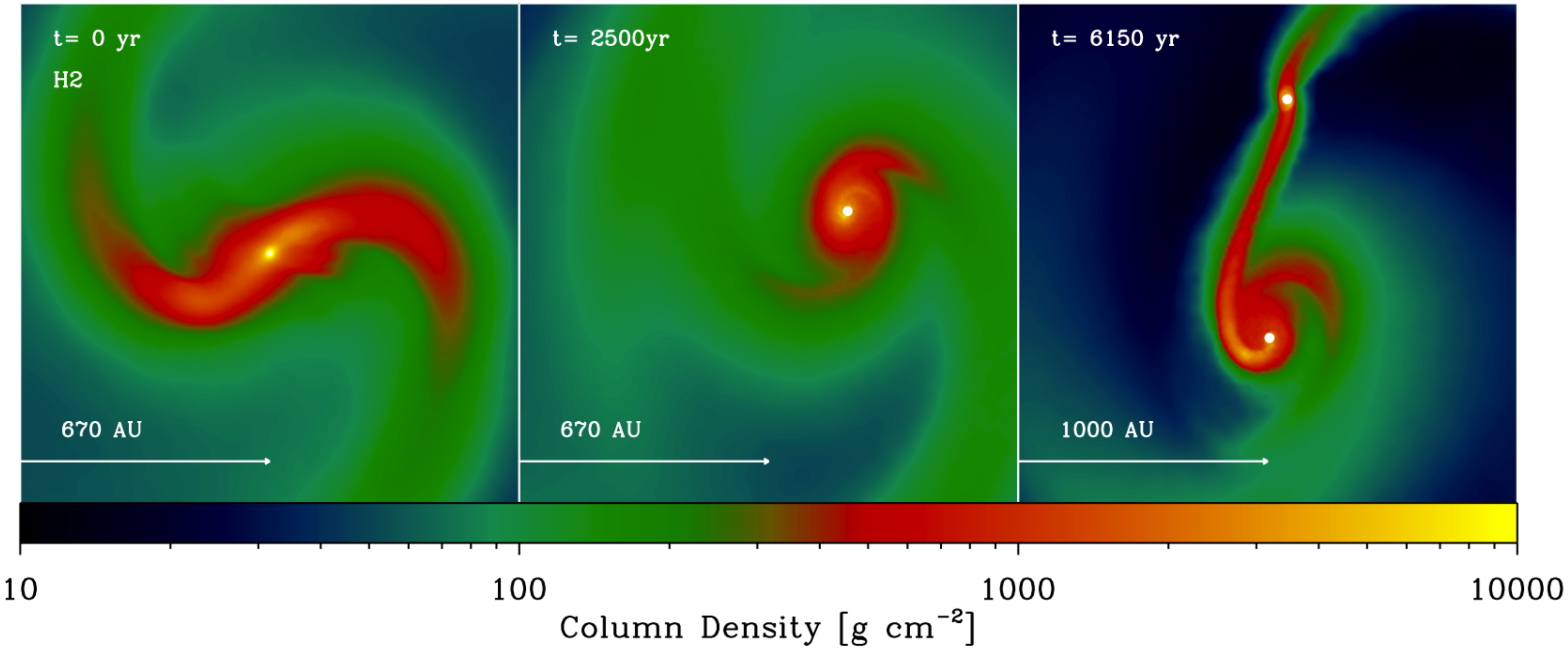
Halo 1

500 yr after first sink formation



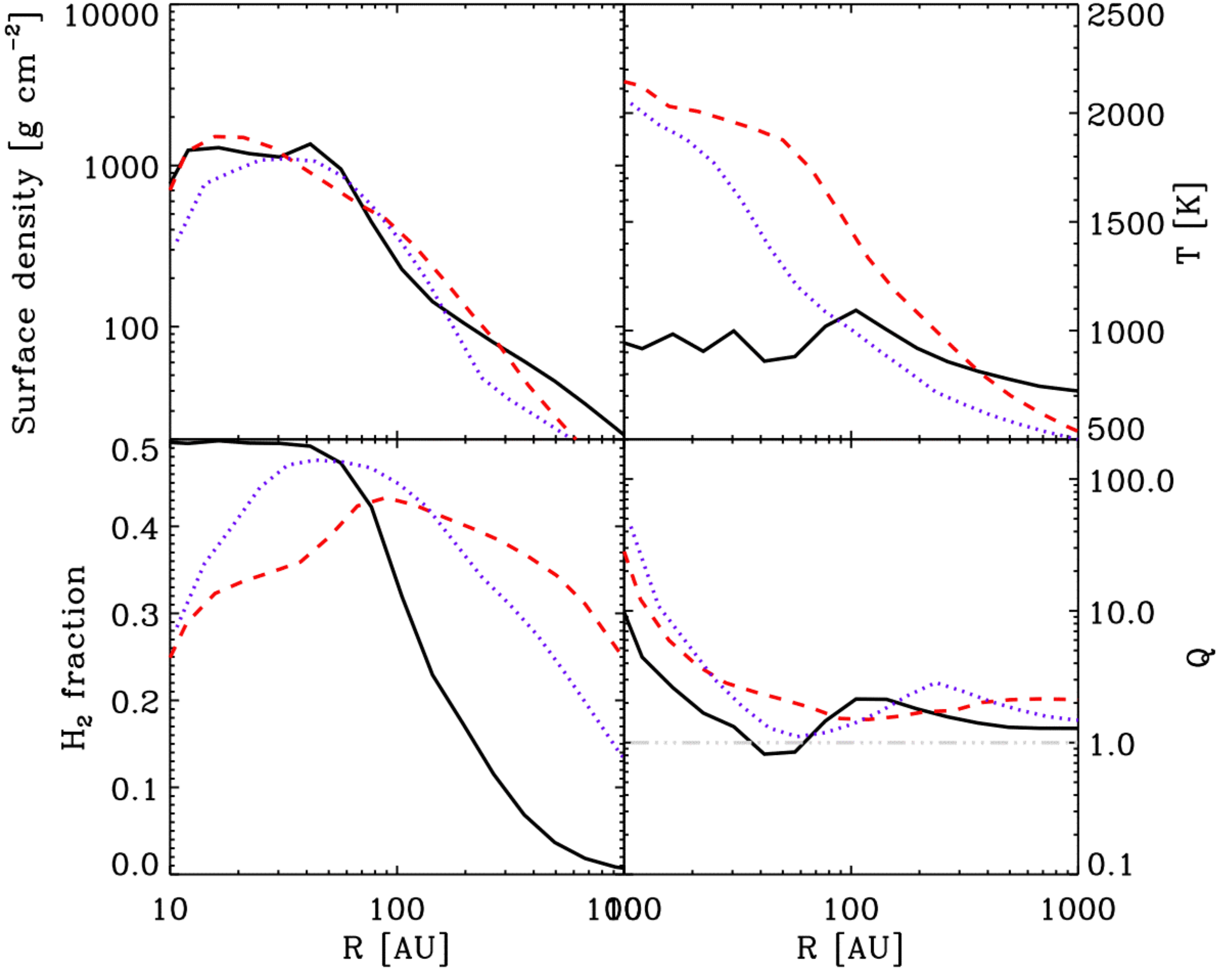
Fragmentation is suppressed in the presense of DMA.

Halo 2



Fragmentation does eventually occur in some cases, but at radii of order 1000 AU.

Disk Stability



Conclusions

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Conclusions

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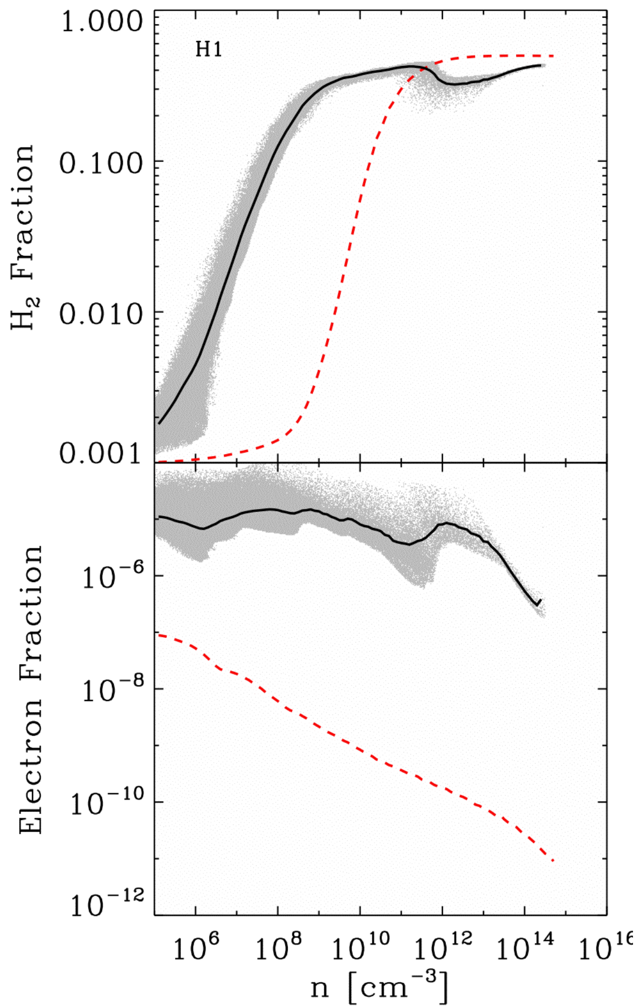
Molecular Hydrogen



May skip this.