On the effects of a hot gas halo in the evolution of isolated galaxy models

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Background

Some spiral galaxies like our own Milky Way Galaxy possesses hot diffuse gas in the halo.

- 5 components: DM halo, stellar disk, stellar bulge, gaseous disk and gaseous halo

Basis:

- Observations
- Cosmological hydrodynamic simulations

However,

only a few numerical studies taking account of halo gas in the models have been presented.

Moster et al. (2011) included, for the first time,
a diffuse rotating hot gaseous halo
as well as the other four components
and performed hydrodynamic simulations of major mergers of disk galaxies.

We also construct galaxy models including a hot gas halo component and study its impact on the galaxy evolution.

Contents

- Numerical Codes
- Initial Galaxy Models
- Simulation Results

The Codes

ICs (galaxy models) generated using the ZENO software package (version 008):
- provided by Joshua E. Barnes
- allows one to build multiple components in mutual equilibrium
  with user-specified density profiles
  in collisionless or gaseous form.

Simulations performed using (an early version of) Gagdet3:
- the Tree-SPH code developed by Volker Springel
- includes radiative cooling, star formation, SN feedback,
  a phenomenological model for galatic winds,
  and sub-resolution model of multiphase ISM (Springel & Hernquist 2003)

Galaxy models

- (Stellar) Bulge
  follows a Hernquist (1990) model
  & tapers at larger radii.

$$\rho_{\rm b}(r) = \begin{cases} \dfrac{a_{\rm b} m_{\rm b}}{2\pi} \dfrac{1}{r(a_{\rm b}+r)^3} & \text{for } r \le b_{\rm b} \\ \rho_{\rm b}^* \left(\dfrac{b_{\rm b}}{r}\right)^2 e^{-2r/b_{\rm b}} & \text{for } r > b_{\rm b} \end{cases}$$

- Star and Gas Disks
  have an exponential radial profile
  & a sech^2 vertical profile.

$$\rho_{\rm d}(R, z) = \frac{M_{\rm d}}{4\pi a_{\rm d}^2 z_{\rm d}} e^{-R/a_{\rm d}} \, \mathrm{sech}^2\left(\frac{z}{z_{\rm d}}\right)$$

- DM Halo
  follows a Navarro et al. (1996) model
  & tapers at larger radii.

$$\rho_{\rm h}(r) = \begin{cases} \dfrac{M_{\rm h}(a_{\rm h})}{4\pi(\ln(2)-\frac{1}{2})} \dfrac{1}{r(r+a_{\rm hc})^2} & \text{for } r \le b_{\rm h} \\ \rho_{\rm h}^* \left(\dfrac{b_{\rm h}}{r}\right)^2 e^{-2\beta(r/b_{\rm h}-1)} & \text{for } r > b_{\rm h} \end{cases}$$

- Gas Halo
  follows either the NFW
  or a non-singular isothermal profile.

$$\rho_{\rm hg}(r) = \frac{f_{\rm norm} M_{\rm hg}}{2\pi\sqrt{\pi}\, b_{\rm hg}} \frac{1}{r^2 + a_{\rm hg}^2} e^{-(r/b_{\rm hg})^2}$$

Galaxy models

Model Parameters

		Model DHi	Model DHi-f5	Model DHn	Model DHn-f5	Model D	Model Hi
Bulge:							
bulge model		Hernquist	Hernquist	Hernquist	Hernquist	Hernquist	Hernquist
a_b [kpc]	Length scale of bulge	0.7	0.7	0.7	0.7	0.7	0.7
b_b [kpc]	Radius at which truncation starts	140.0	140.0	140.0	140	140.0	140
M_b [10^{10} $M_\odot$]	Total mass of bulge	1	1	1	1	1	1
N_b	Particle numbers in the gas disk	8192	8192	8192	8192	8192	8192
Star disk							
disk model		exponential	exponential	exponential	exponential	exponential	exponential
a_{ds}	Length scale of star disk	3.5	3.5	3.5	3.5	3.5	3.5
z_{ds}	Vertical scale height	0.35	0.35	0.35	0.35	0.35	0.35
b_{ds}	Outer disk cutoff radius	42	42	42	42	42	42
M_{ds}	Total mass of star disk	4.4	4.4	4.4	4.4	4.4	5.0
N_{ds}	Particle numbers in star disk	16384	16384	16384	16384	16384	16384
Gas disk							
disk model		exponential	exponential	exponential	exponential	exponential	...
a_{dg}	Length scale of gas disk	8.75	8.75	8.75	8.75	8.75	...
z_{dg}	Vertical scale height	0.35	0.35	0.35	0.35	0.35	...
b_{dg}	Outer disk cutoff radius	105	105	105	105	105	...
M_{dg}	Total mass of gas disk	0.6	0.6	0.6	0.6	0.6	...
N_{dg}	Particle numbers in gas disk	16384	16384	16384	16384	16384	...
DM halo:							
halo model		NFW	NFW	NFW	NFW	NFW	NFW
a_{hd}	Radial scale of DM halo	21	21	21	21	21	21
b_{hd}	Radius to begin taper	84	84	84	84	84	84
$M_{hd}(a_{hd})$	Mass within radius a_h	12.23	11.74	12.23	11.74	12.35	12.23
$M_{hd}(\infty) = M_{hd}$	Total mass of DM halo	118.8	114.0	118.8	114.0	120	118.8
N_{hd}	Particle numbers in DM halo	163840	163840	163840	163840	163840	163840
Gas halo:							
halo model		isothermal	isothermal	NFW	NFW	...	isothermal
a_{hg}	Radial scale, or	...	...	21	21	...	...
	radius of core	10.5	10.5	...	...	...	10.5
b_{hg}	Radius to begin taper, or	...	...	84.0	84.0	...	...
	radius of taper	420	420	...	...	...	420
$M_{hg}(a_{hg})$	Mass within radius a_{hg}	...	...	0.12	0.62	...	...
M_{hg}	Total mass of gas halo	1.2	6.0	1.2	6.0	...	1.2
N_{hg}	Particle numbers in gas halo	32768	163840	32768	163840	...	32768

Galaxy models

Our primary goal:

to study the effects of a hot gaseous halo on galaxy evolution

Different types of our models:

- Type DH: 3 collisionless components + gas disk & gas halo
    - Type DHi: Isothermal gas halo
    - Type DHn: NFW gas halo
- Type D: 3 collisionless components + gas disk
- Type H: 3 collisionless components + gas halo

In all our models:

$M_{tot}=M_b + M_d + M_h = 126 \times 10^{10}\ M_\odot$

$M_b = 1 \times 10^{10}\ M_\odot$

$M_d = M_{ds} + M_{dg} = 5 \times 10^{10}\ M_\odot$

$M_h = M_{hd} + M_{hg} = 120 \times 10^{10}\ M_\odot$

Galaxy models

Galaxy Models (w/o winds)

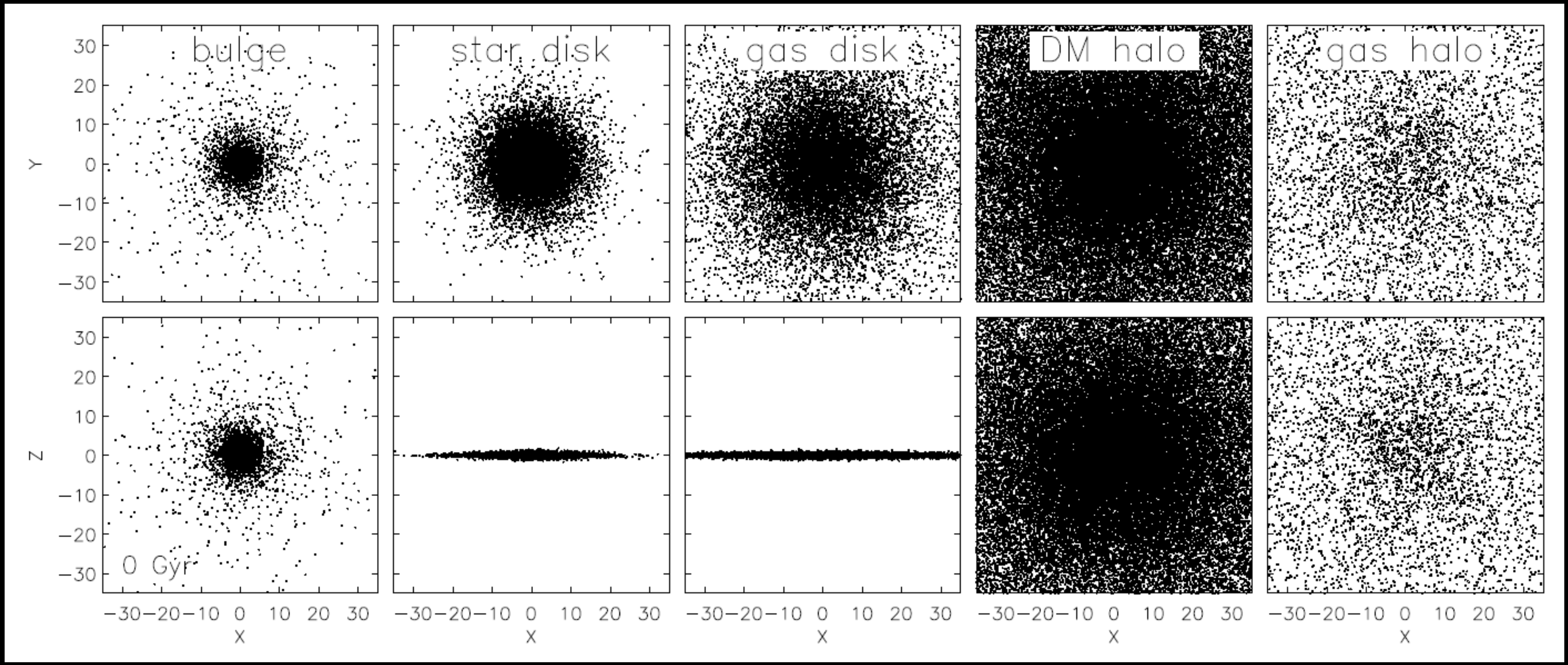
Model name	Gas halo model	Gas halo rotation	f_{hg}	f_{dg}
DHi	isothermal	...	0.01	0.12
DHi-f5	isothermal	...	0.05	0.12
DHir	isothermal	gas disk rotation×0.5	0.01	0.12
DHn	NFW	...	0.01	0.12
DHn-f5	NFW	...	0.05	0.12
D	...	...	...	0.12
Hi	isothermal	...	0.01	...

Wind test runs (with winds)

Model	Wind mode	WindEffi	WindFreeTravelLength	WindEnergyFract	WindFreeTrevelDensFac
DHir-Wa	axial	2	20	1	0.1
D-Wa	axial	2	20	1	0.1

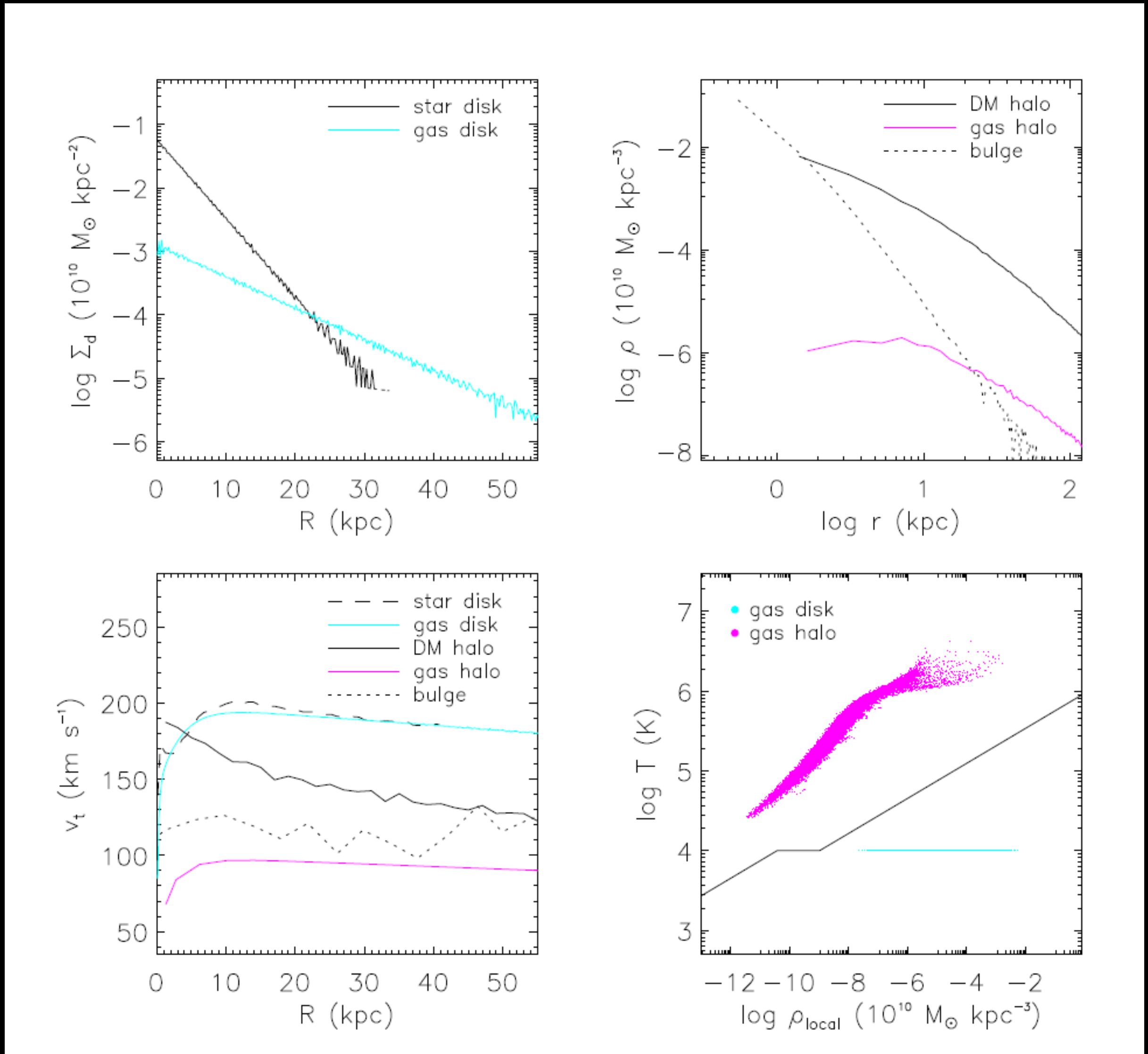
Galaxy Models

Model DHi (& DHir) at t=0



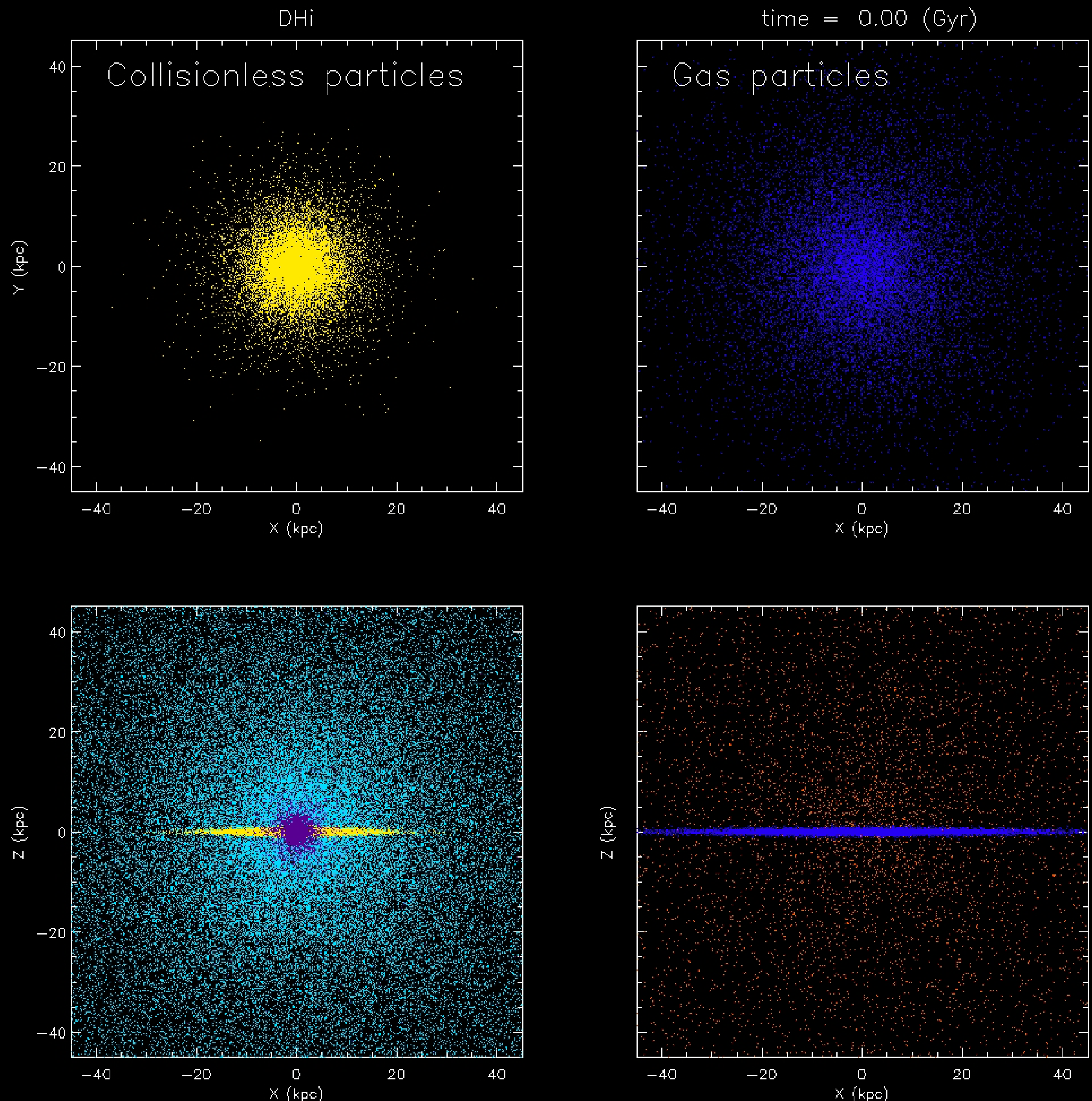
Galaxy Models

Model DHi (& DHir) at t=0



Evolution:

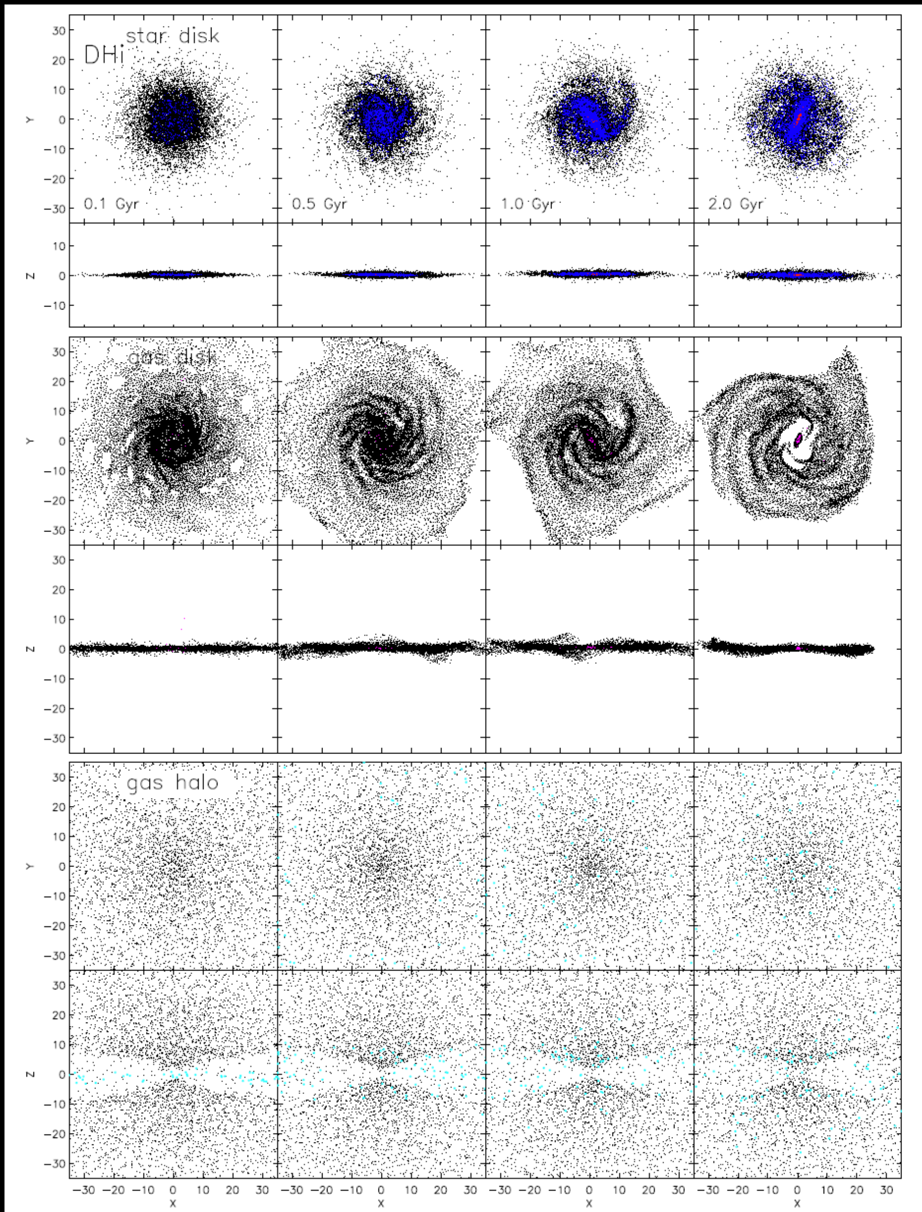
1. DHi
2. DHi-f5
3. DHir
4. DHn
5. DHn-f5
6. D
7. Hi



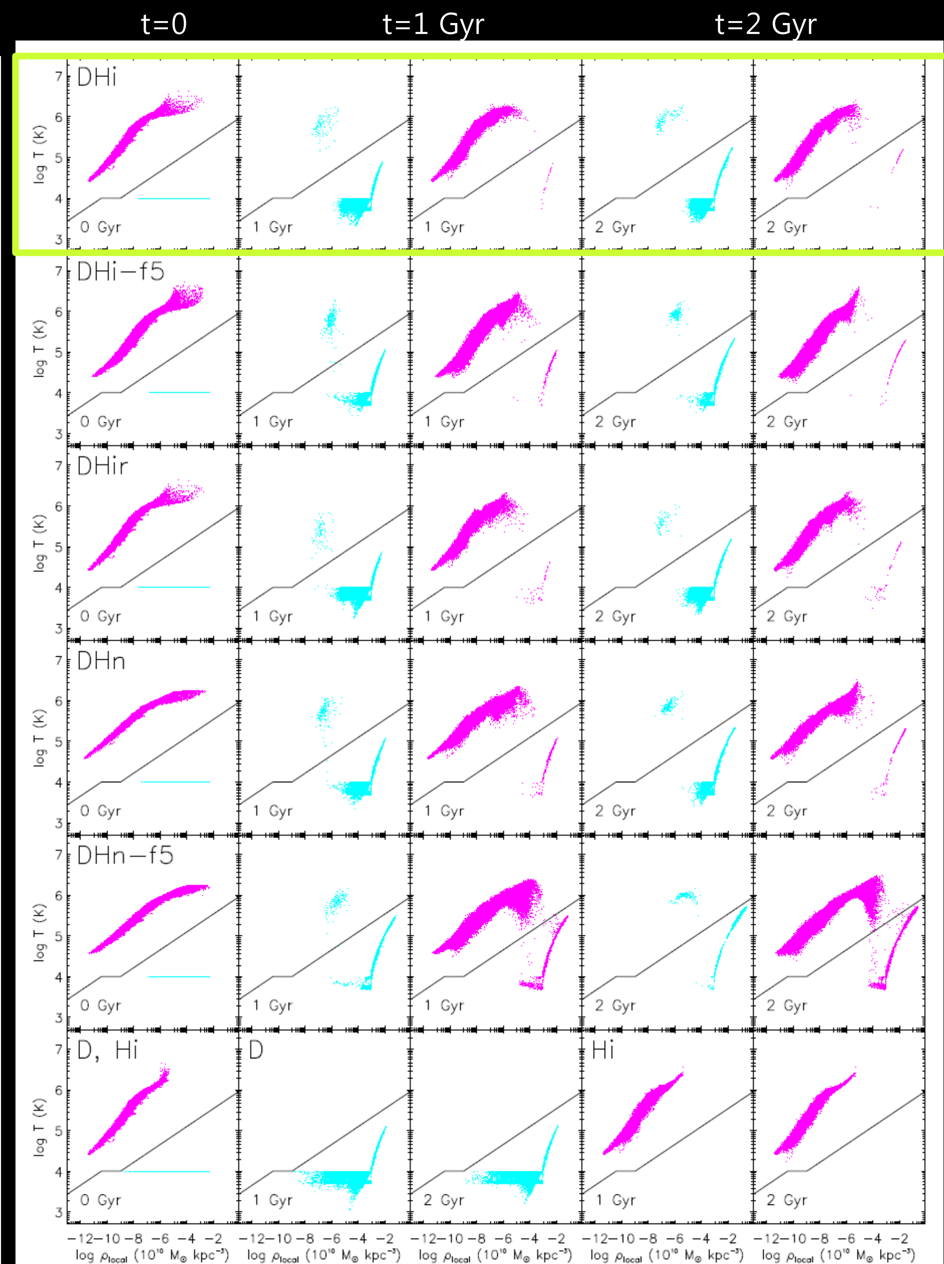
DHi
time = 0.00 (Gyr)
Collisionless particles
Gas particles
Y (kpc)
Z (kpc)
X (kpc)
40
20
0
−20
−40

1. Model DHi

Gas halo: Isothermal, f_{hg}=0.01, M_{hg}=1.2 X 10^{10} $M_\odot$, N_{hg}= 32768
Gas disk: Exponential, f_{dg}=0.12, M_{dg}=0.6 X 10^{10} $M_\odot$, N_{dg}= 16384

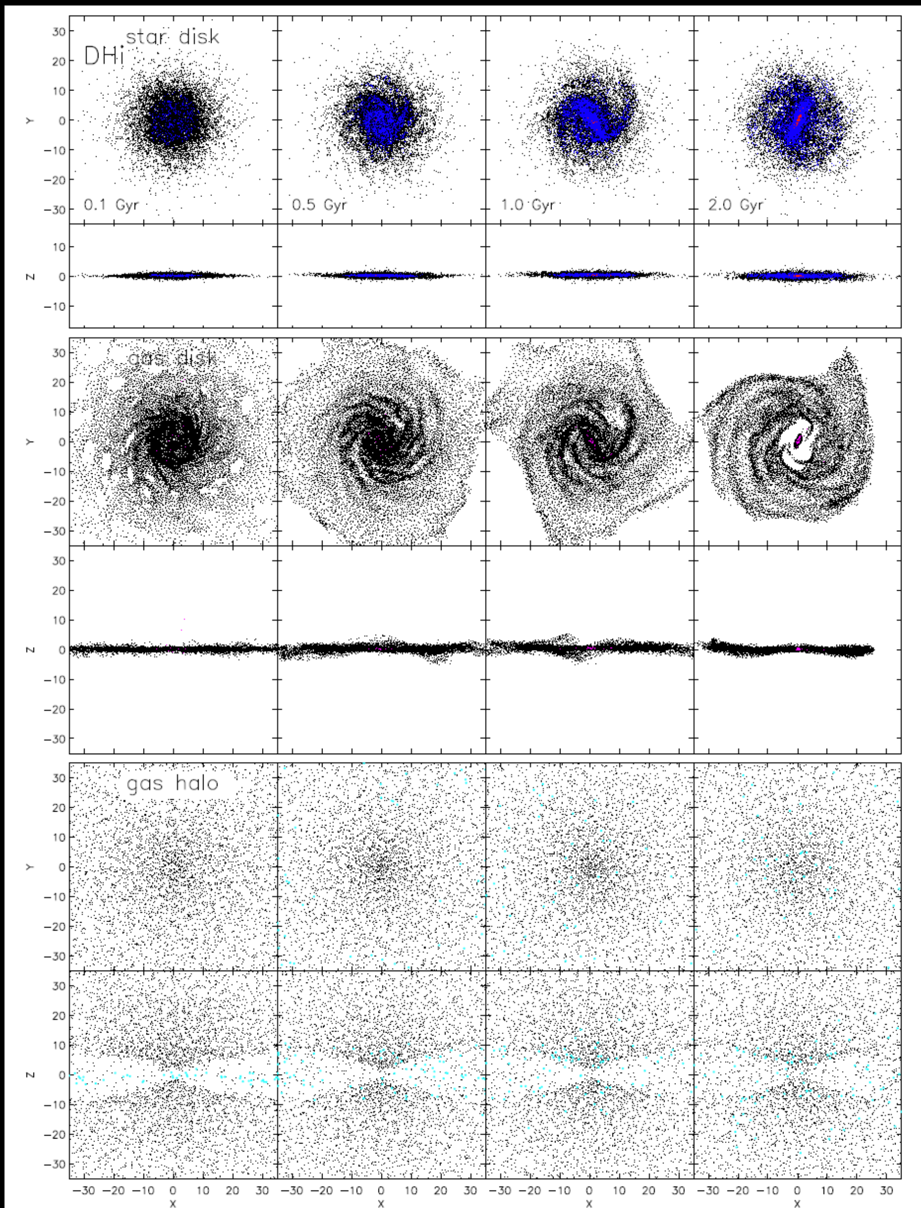


Temperature vs Local Density



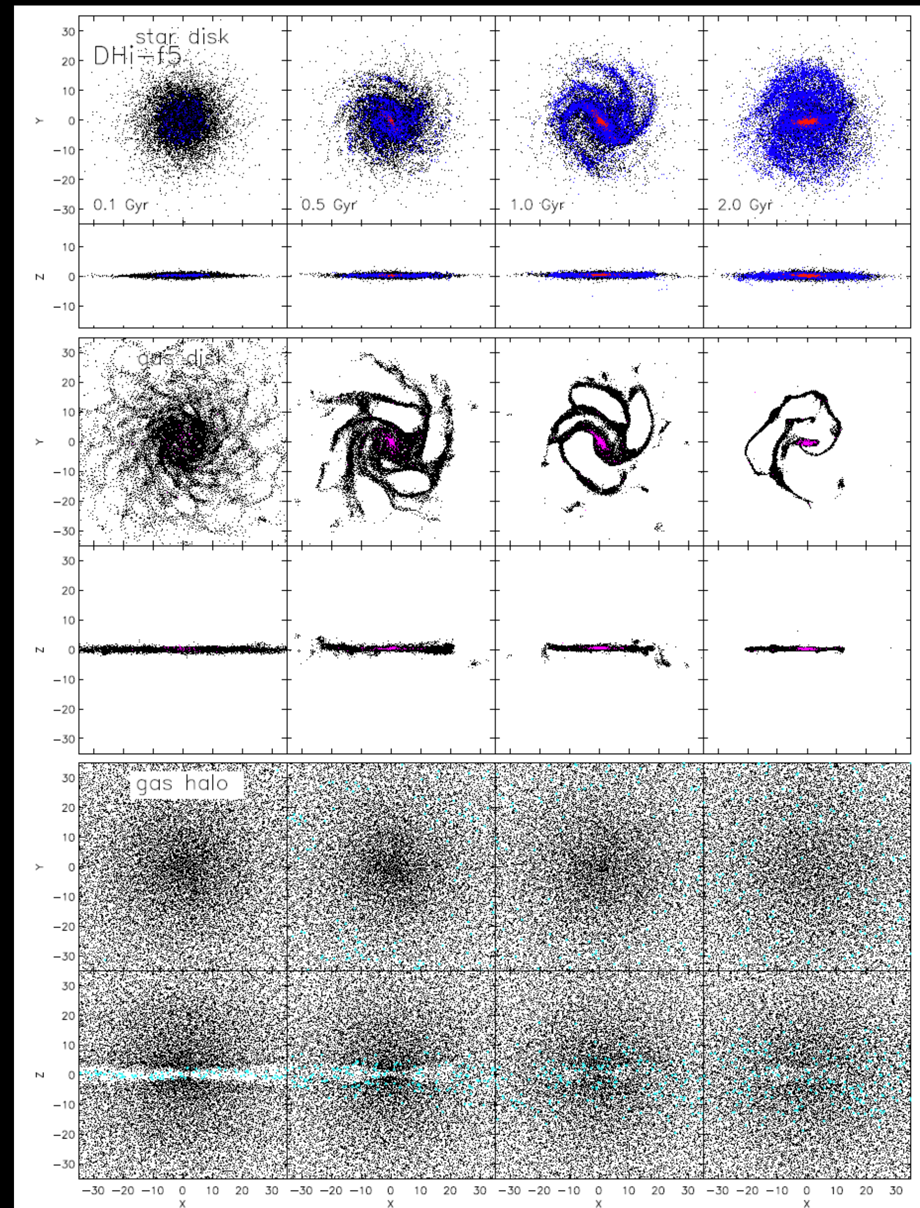
1. Model DHi

Gas halo: Isothermal, f_{hg}=0.01, M_{hg}=1.2 X 10^{10} $M_{\odot}$, N_{hg}= 32768
Gas disk: Exponential, f_{dg}=0.12, M_{dg}=0.6 X 10^{10} $M_{\odot}$, N_{dg}= 16384



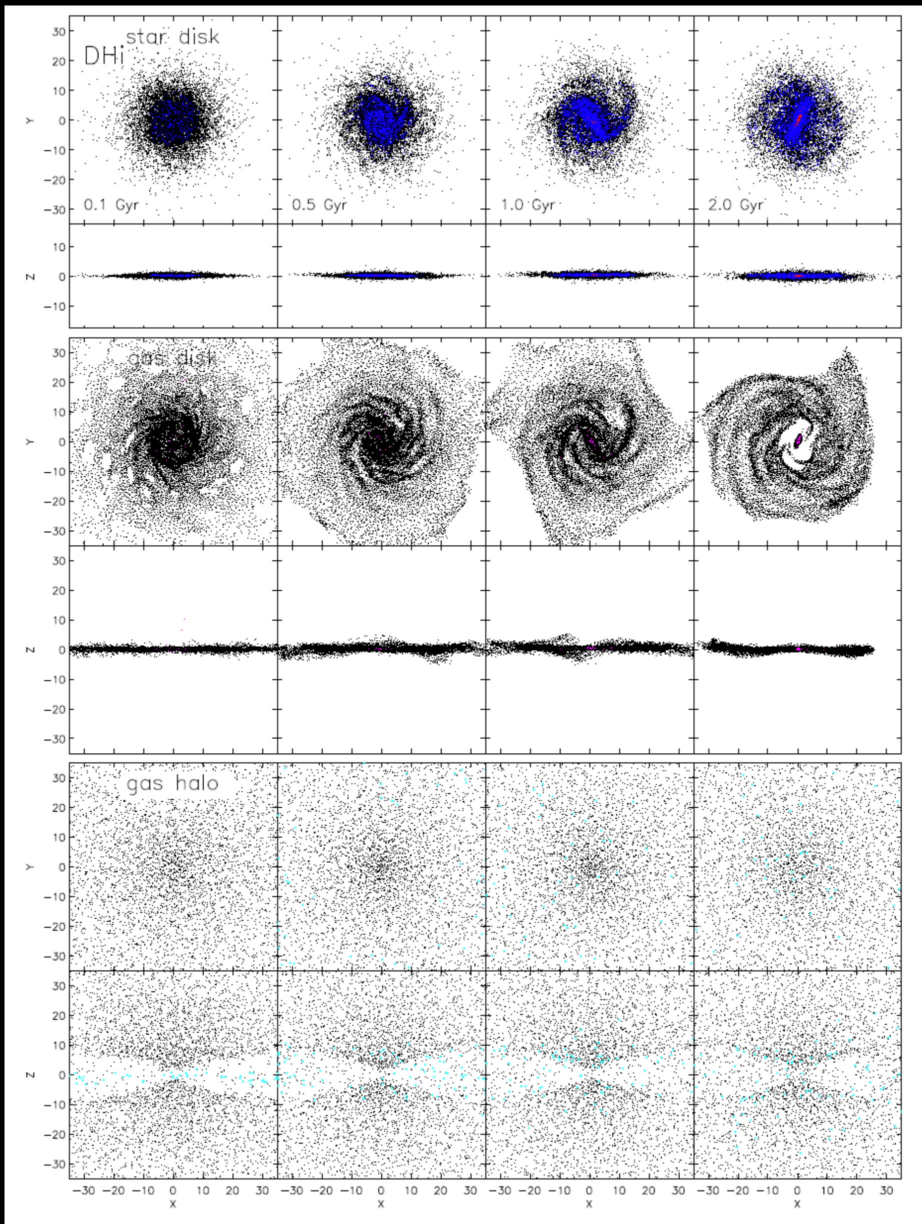
2. Model DHi-f5

Gas halo: Isothermal, f_{hg}=0.05, M_{hg}=6.0 X 10^{10} $M_{\odot}$, N_{hg}= 163840
Gas disk: Exponential, f_{dg}=0.12, M_{dg}=0.6 X 10^{10} $M_{\odot}$, N_{dg}= 16384



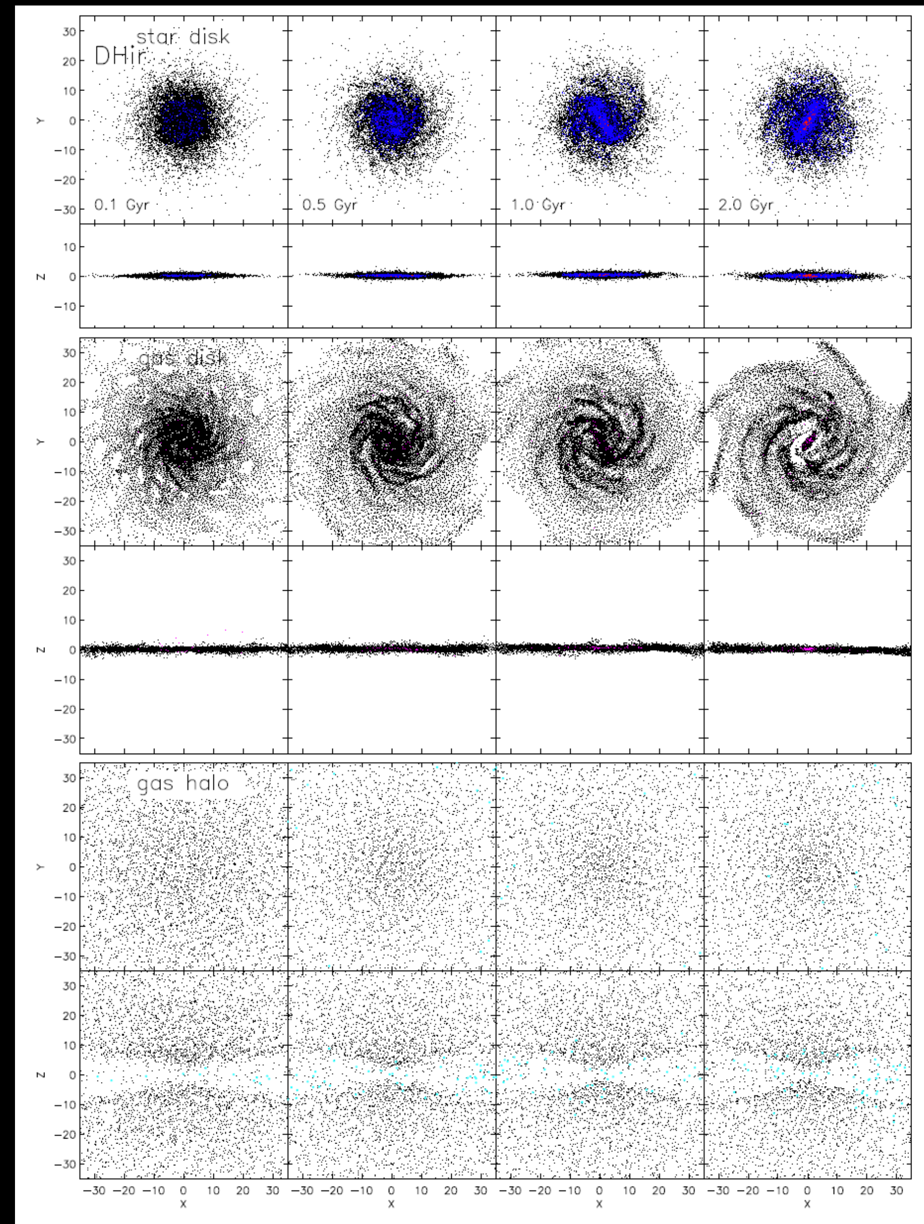
1. Model DHi

Gas halo: Isothermal, f_{hg}=0.01, M_{hg}=1.2 X 10^{10} $M_{\odot}$, N_{hg}= 32768
Gas disk: Exponential, f_{dg}=0.12, M_{dg}=0.6 X 10^{10} $M_{\odot}$, N_{dg}= 16384



3. Model DHir

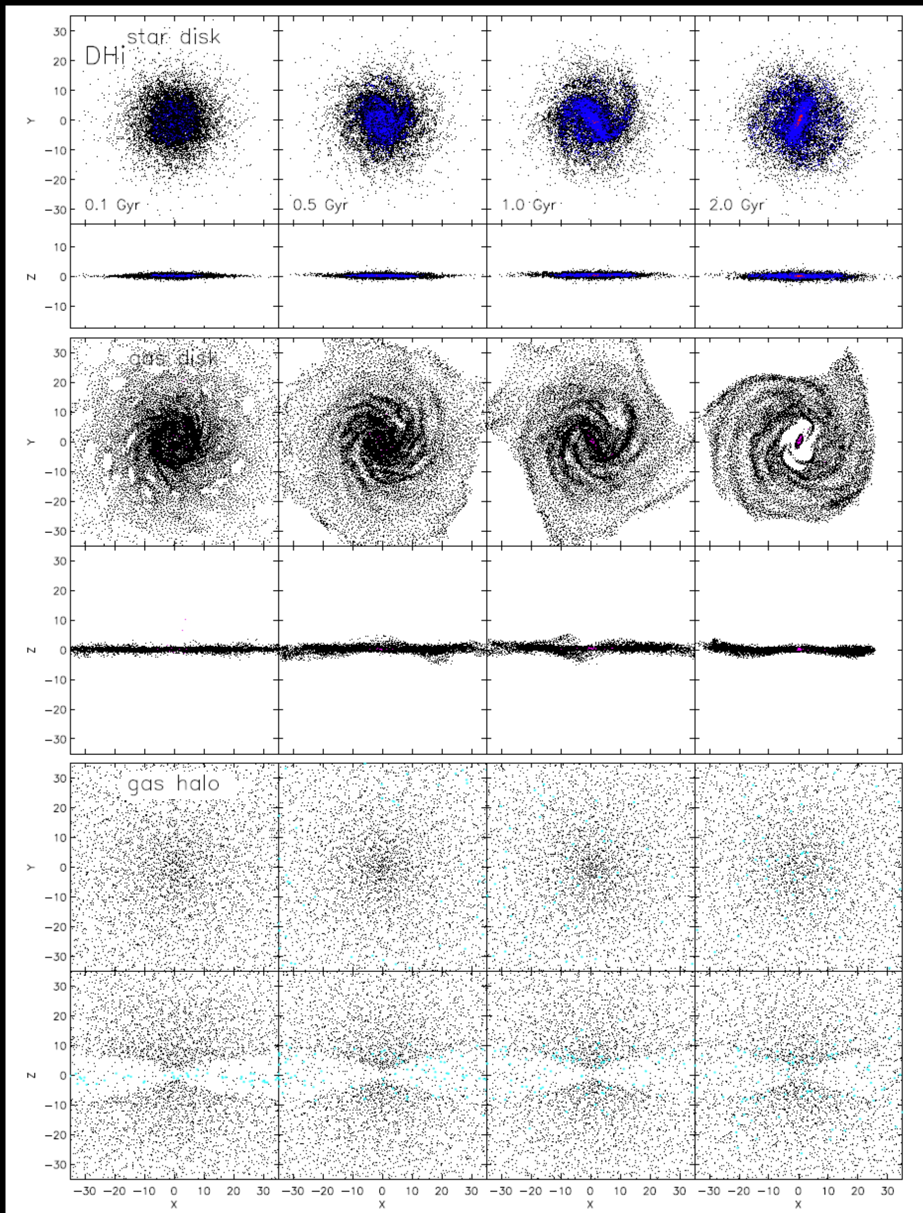
Gas halo: Isothermal+Spin, f_{hg}=0.01, M_{hg}=1.2 X 10^{10} $M_{\odot}$, N_{hg}= 32768
Gas disk: Exponential, f_{dg}=0.12, M_{dg}=0.6 X 10^{10} $M_{\odot}$, N_{dg}= 16384



1. Model DHi

Gas halo: Isothermal, $f_{hg}=0.01$, $M_{hg}=1.2 \times 10^{10}\ M_\odot$, $N_{hg}= 32768$

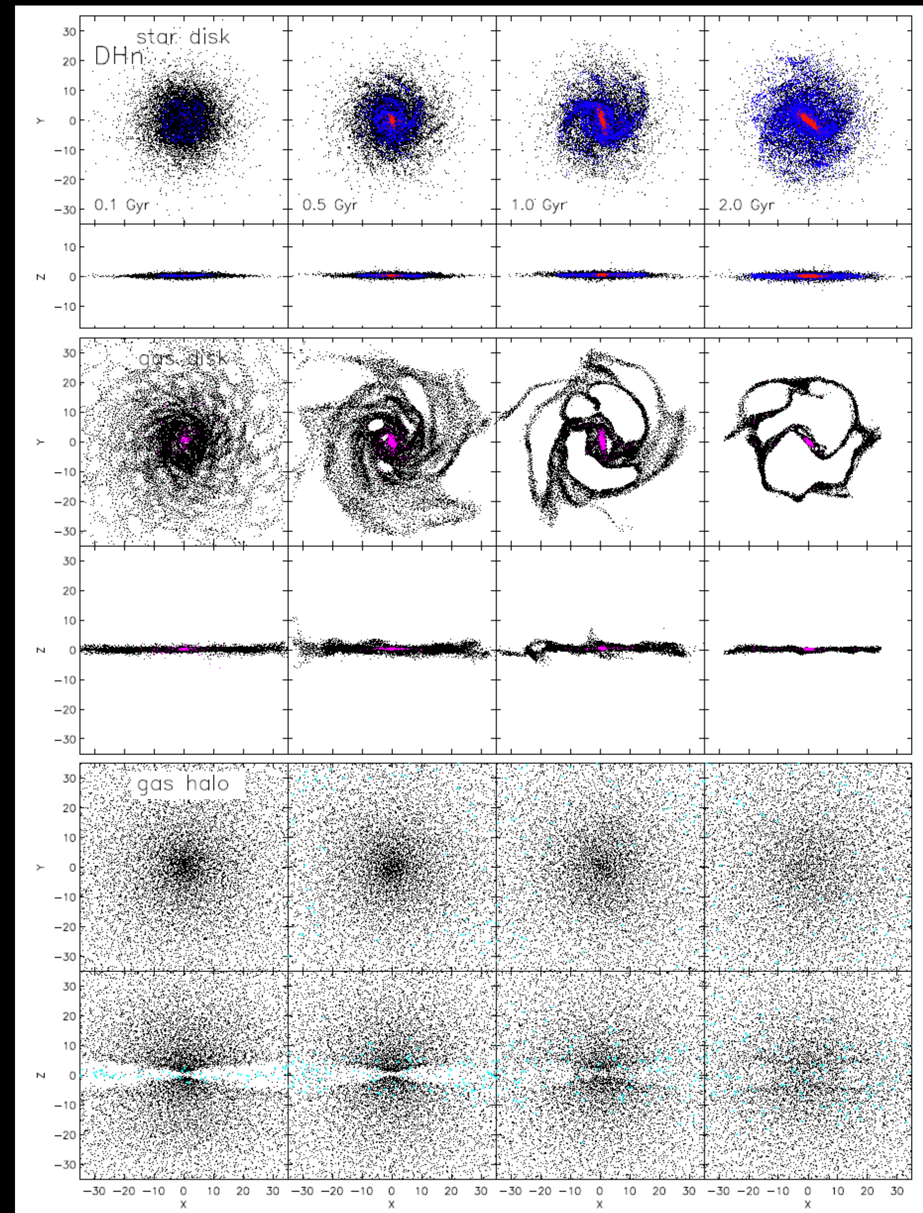
Gas disk: Exponential, $f_{dg}=0.12$, $M_{dg}=0.6 \times 10^{10}\ M_\odot$, $N_{dg}= 16384$



4. Model DHn

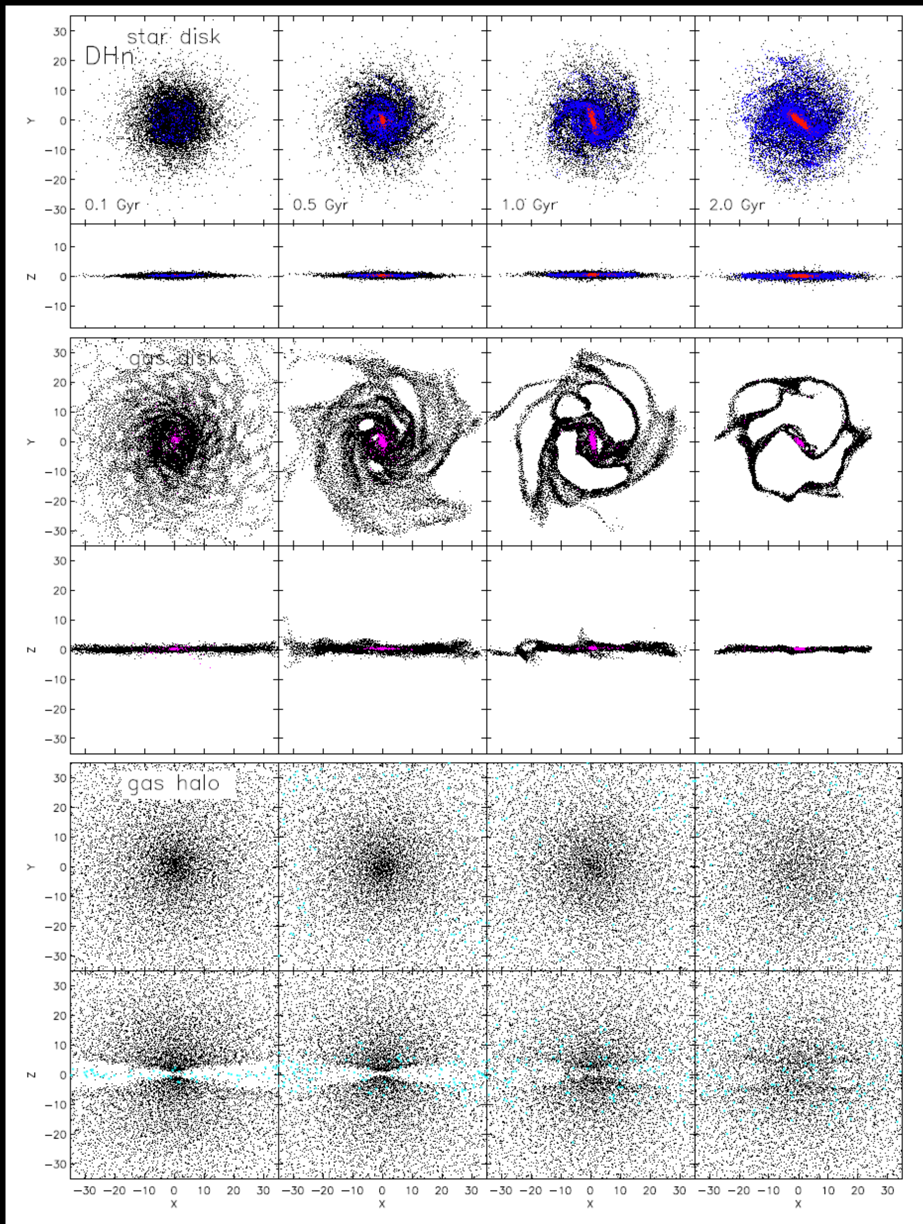
Gas halo: NFW, $f_{hg}=0.01$, $M_{hg}=1.2 \times 10^{10}\ M_\odot$, $N_{hg}= 32768$

Gas disk: Exponential, $f_{dg}=0.12$, $M_{dg}=0.6 \times 10^{10}\ M_\odot$, $N_{dg}= 16384$



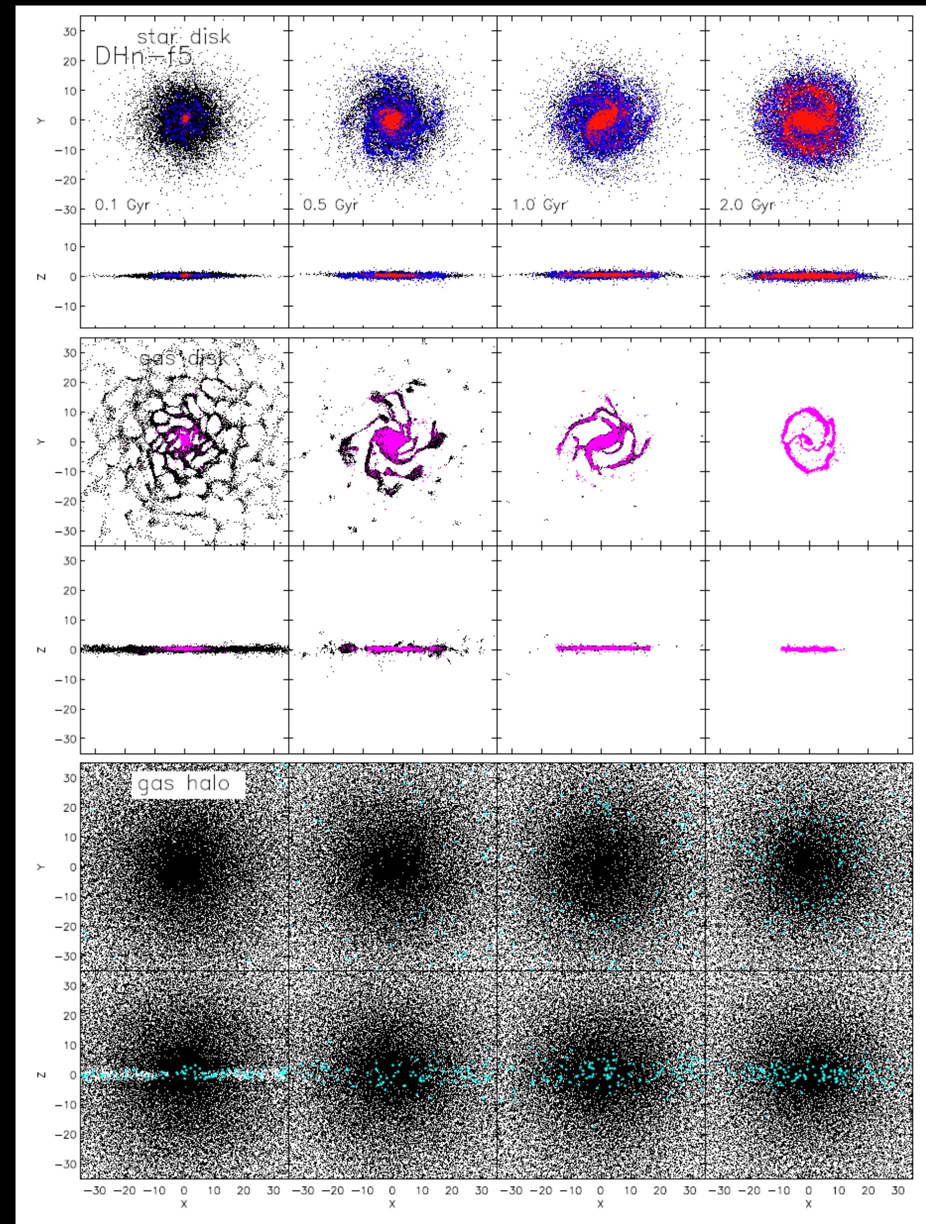
4. Model DHn

Gas halo: NFW, f_{hg}=0.01, M_{hg}=1.2 X 10^{10} $M_{\odot}$, N_{hg}= 32768
Gas disk: Exponential, f_{dg}=0.12, M_{dg}=0.6 X 10^{10} $M_{\odot}$, N_{dg}= 16384



5. Model DHn-f5

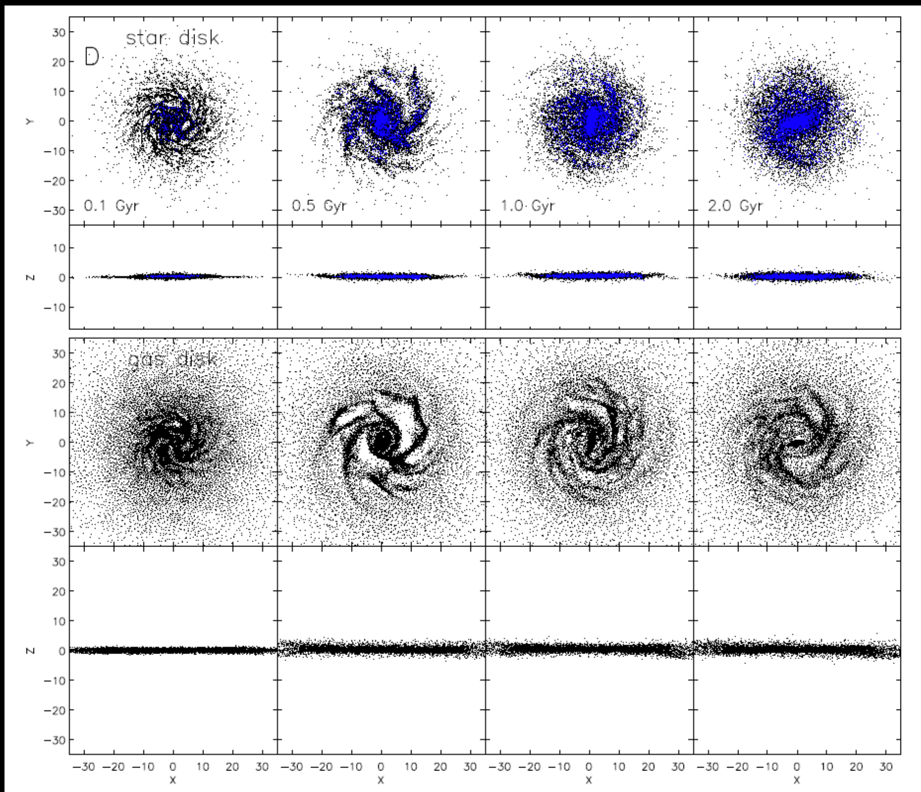
Gas halo: NFW, f_{hg}=0.05, M_{hg}=6.0 X 10^{10} $M_{\odot}$, N_{hg}= 163840
Gas disk: Exponential, f_{dg}=0.12, M_{dg}=0.6 X 10^{10} $M_{\odot}$, N_{dg}= 16384



6. Model D

Gas halo: N/A

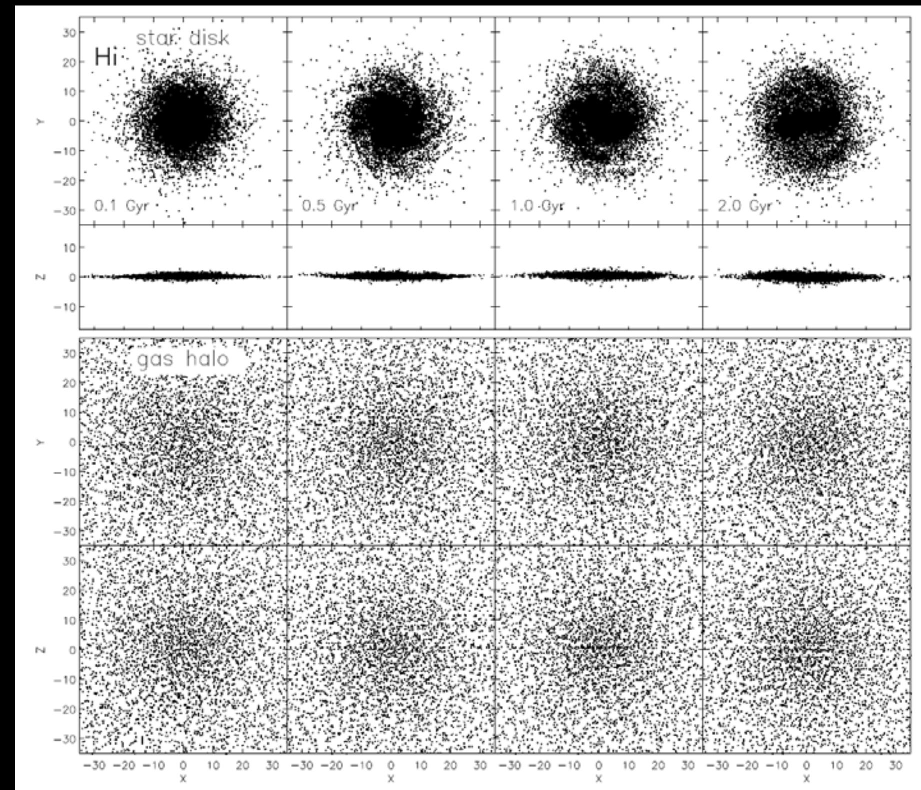
Gas disk: Exponential, f_{dg}=0.12, M_{dg}=0.6 X 10^{10} $M_{\odot}$, N_{dg}= 16384



7. Model Hi

Gas halo: Isothermal, f_{hg}=0.01, M_{hg}=1.2 X 10^{10} $M_{\odot}$, N_{hg}= 32768

Gas disk: N/A



Wind Test Runs:

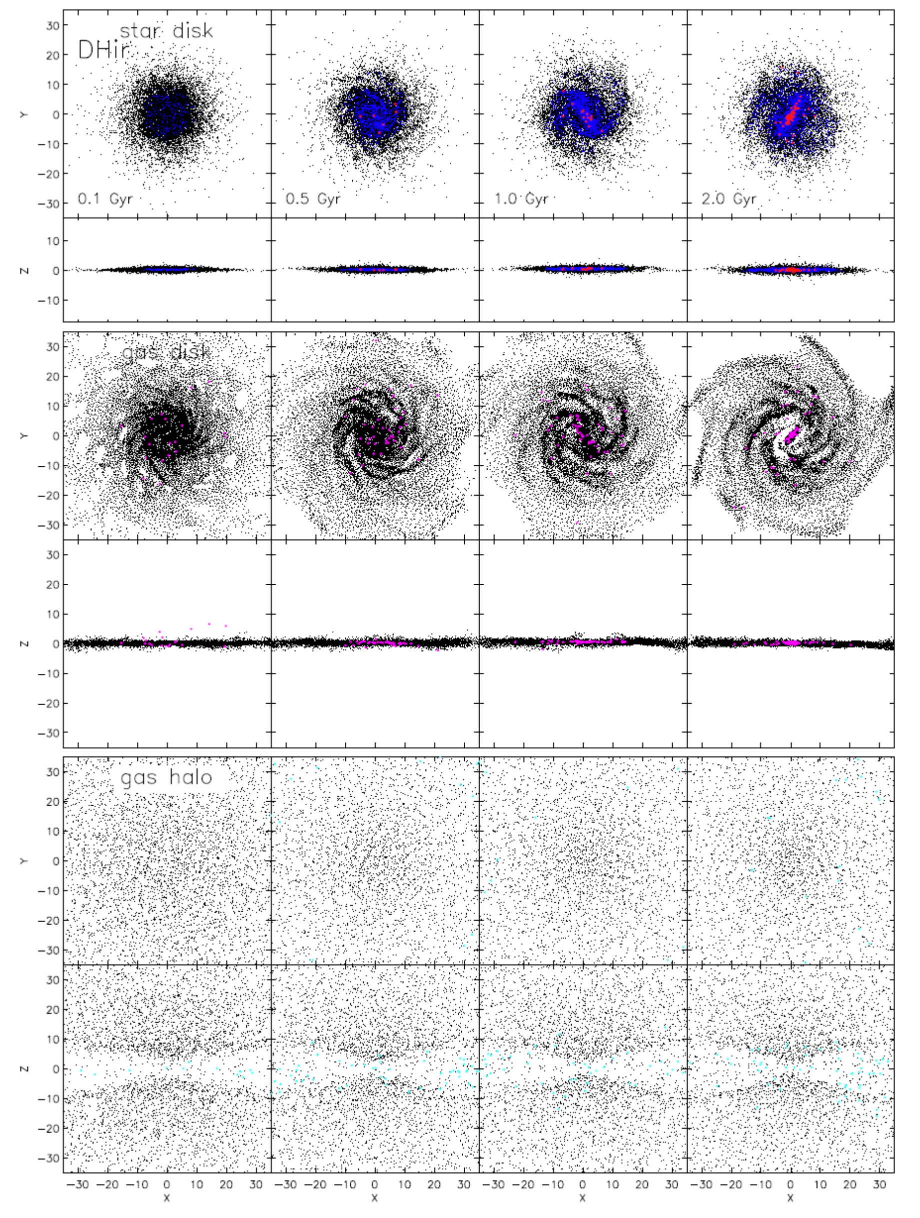
Set1-1 DHi
Set1-2 DHi-f5
Set1-3 DHir
Set1-4 DHn
Set1-5 DHn-f5
Set1-6 D
Set1-7 Hi

Set2-1 DHir-Wa
Set2-2 D-Wa

Model DHir

Gas halo: Isothermal+Spin, f_{hg}=0.01, M_{hg}=1.2 X 10^{10} $M_{\odot}$, N_{hg}= 32768

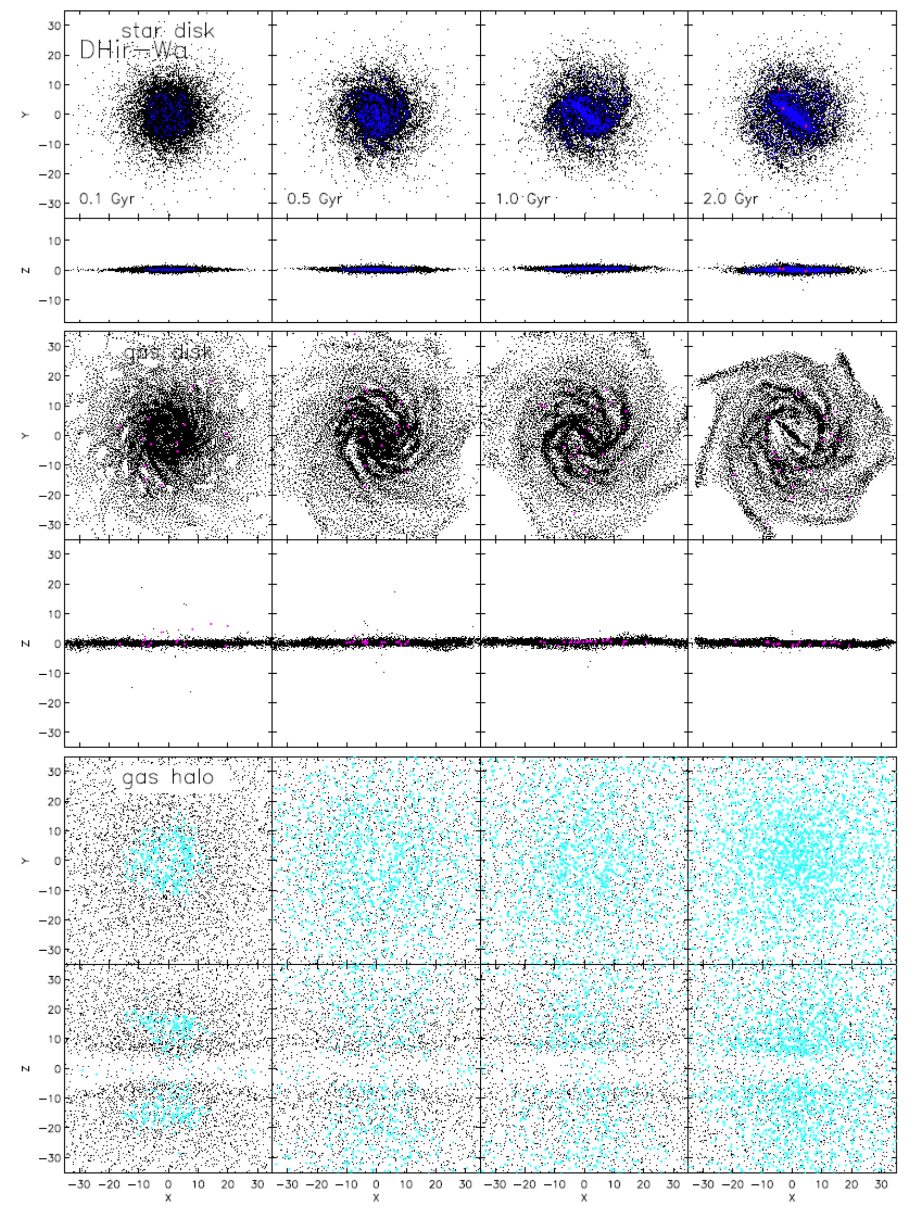
Wind: N/A



(with Winds) Model DHir-Wa

Gas halo: Isothermal+Spin, f_{hg}=0.01, M_{hg}=1.2 X 10^{10} $M_{\odot}$, N_{hg}= 32768

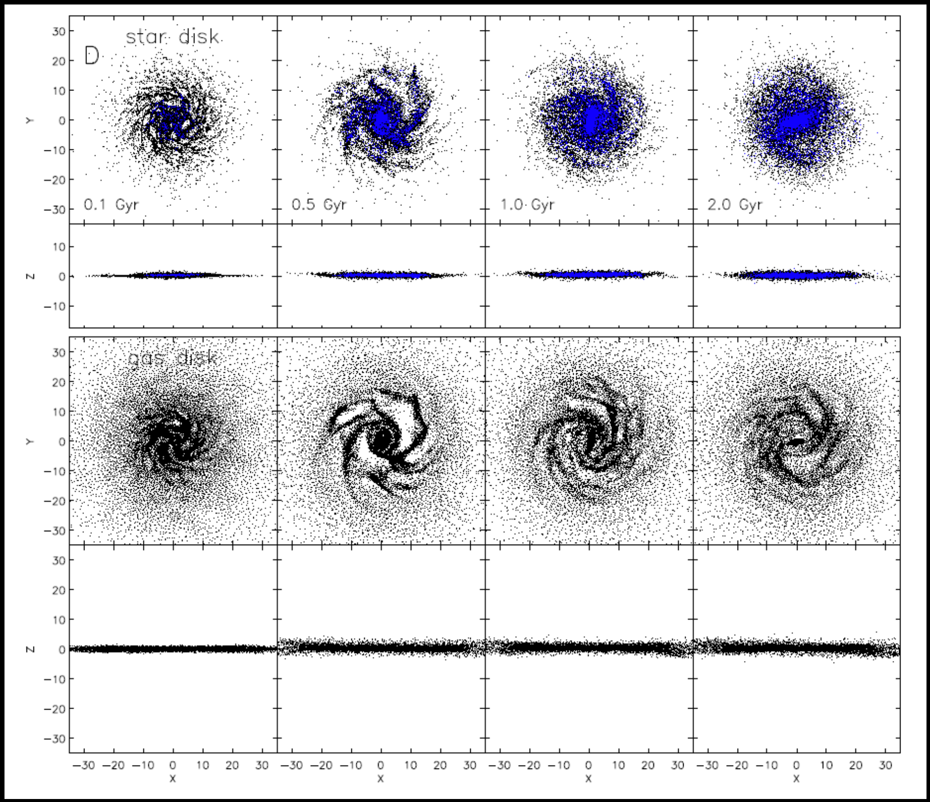
Wind: Axial mode, Wind efficiency=2



Model D

Gas disk: Exponential, f_{dg}=0.12, M_{dg}=0.6 X 10^{10} $M_{\odot}$, N_{dg}= 16384

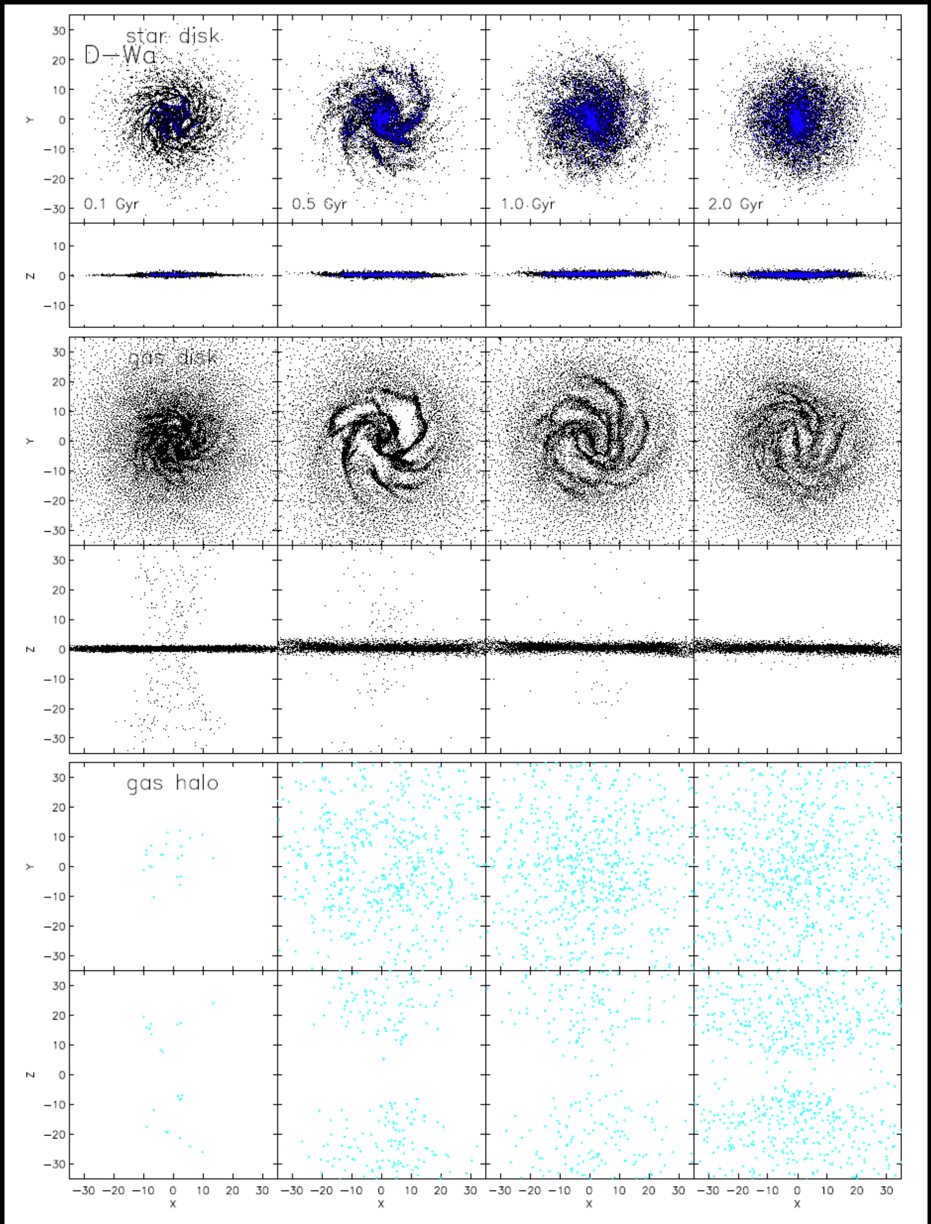
Wind: N/A



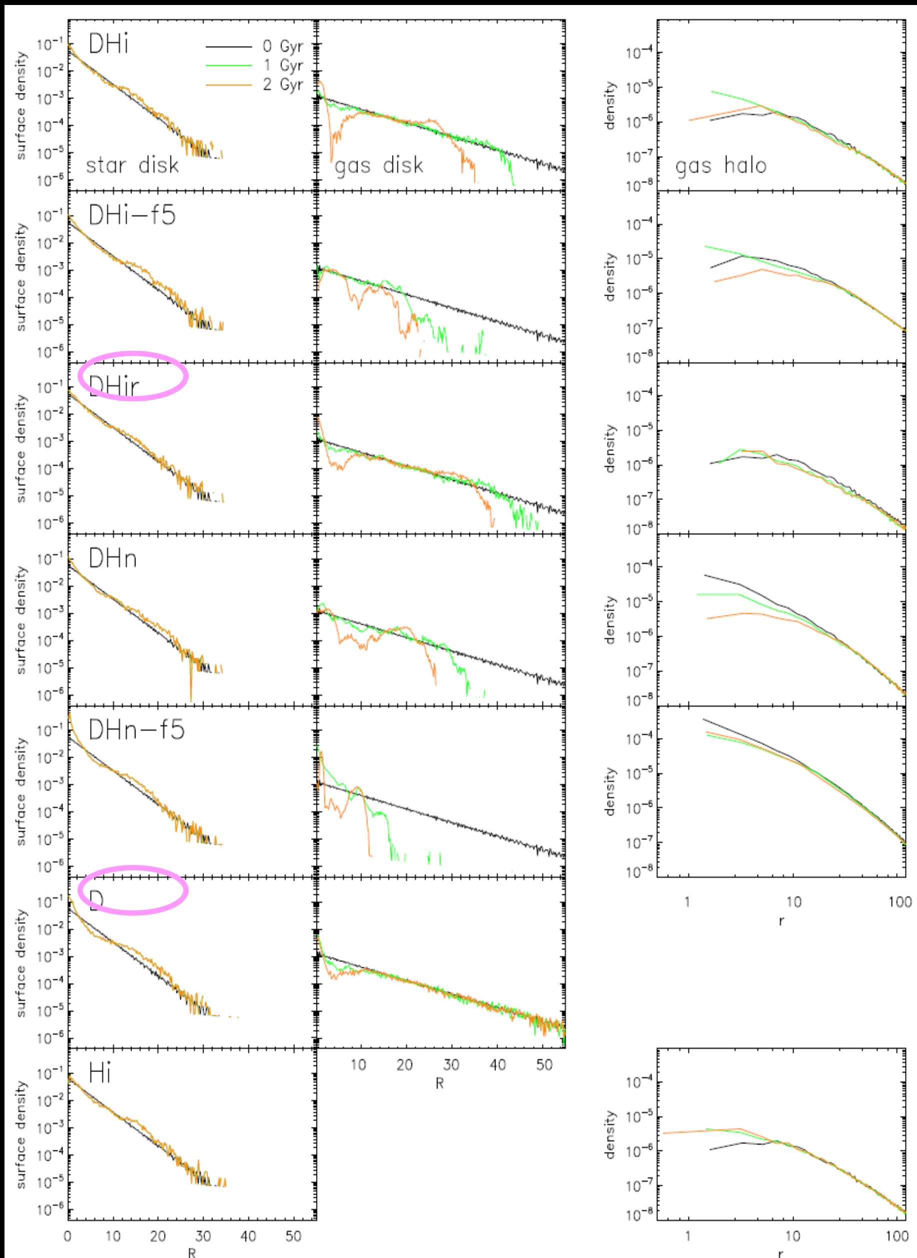
(with Winds)Model D-Wa

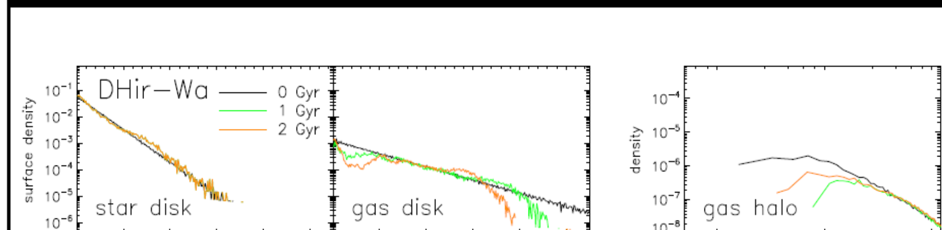
Gas disk: Exponential, f_{dg}=0.12, M_{dg}=0.6 X 10^{10} $M_{\odot}$, N_{dg}= 16384

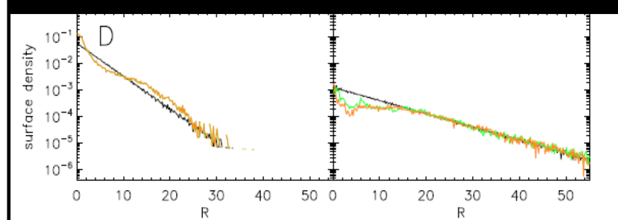
Wind: Isotropic mode, Wind efficiency=2



Density Profiles



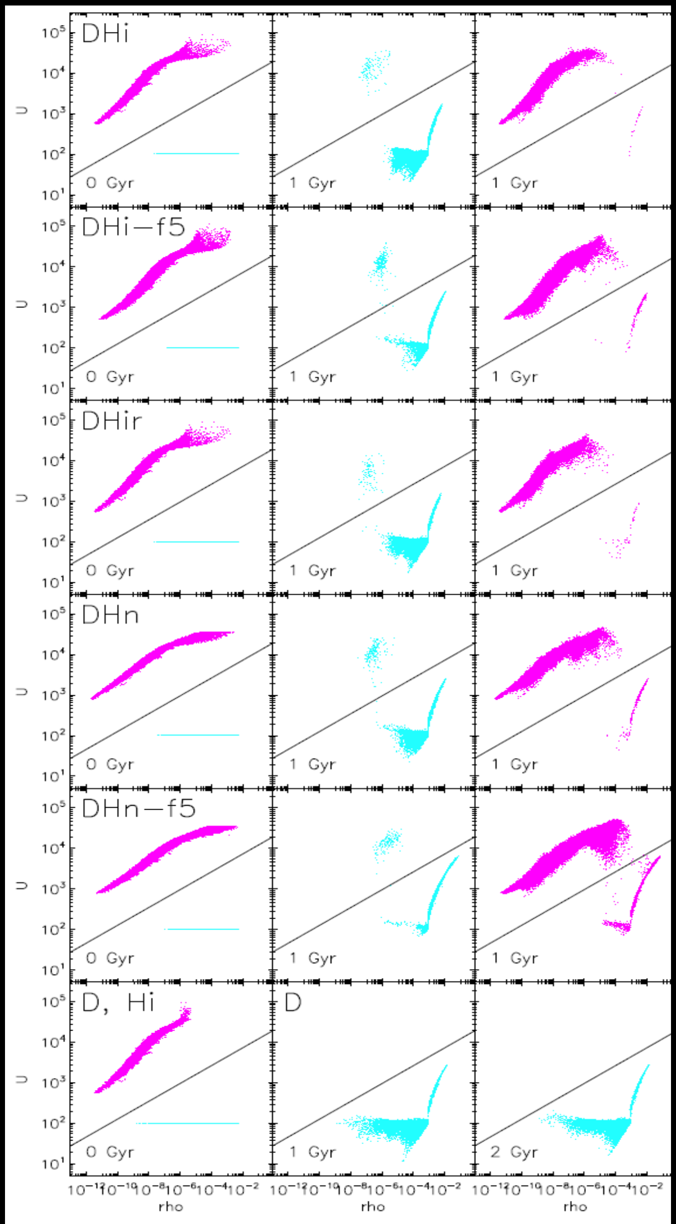




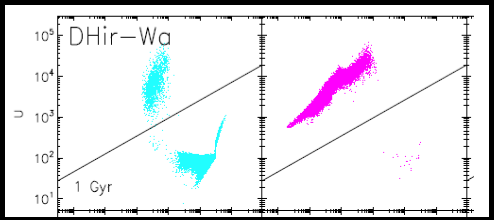
Internal Energy vs Local Density

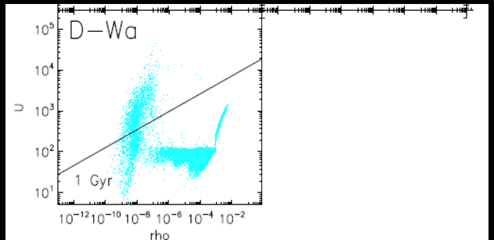
t=0

(Set 1) t=1 Gyr

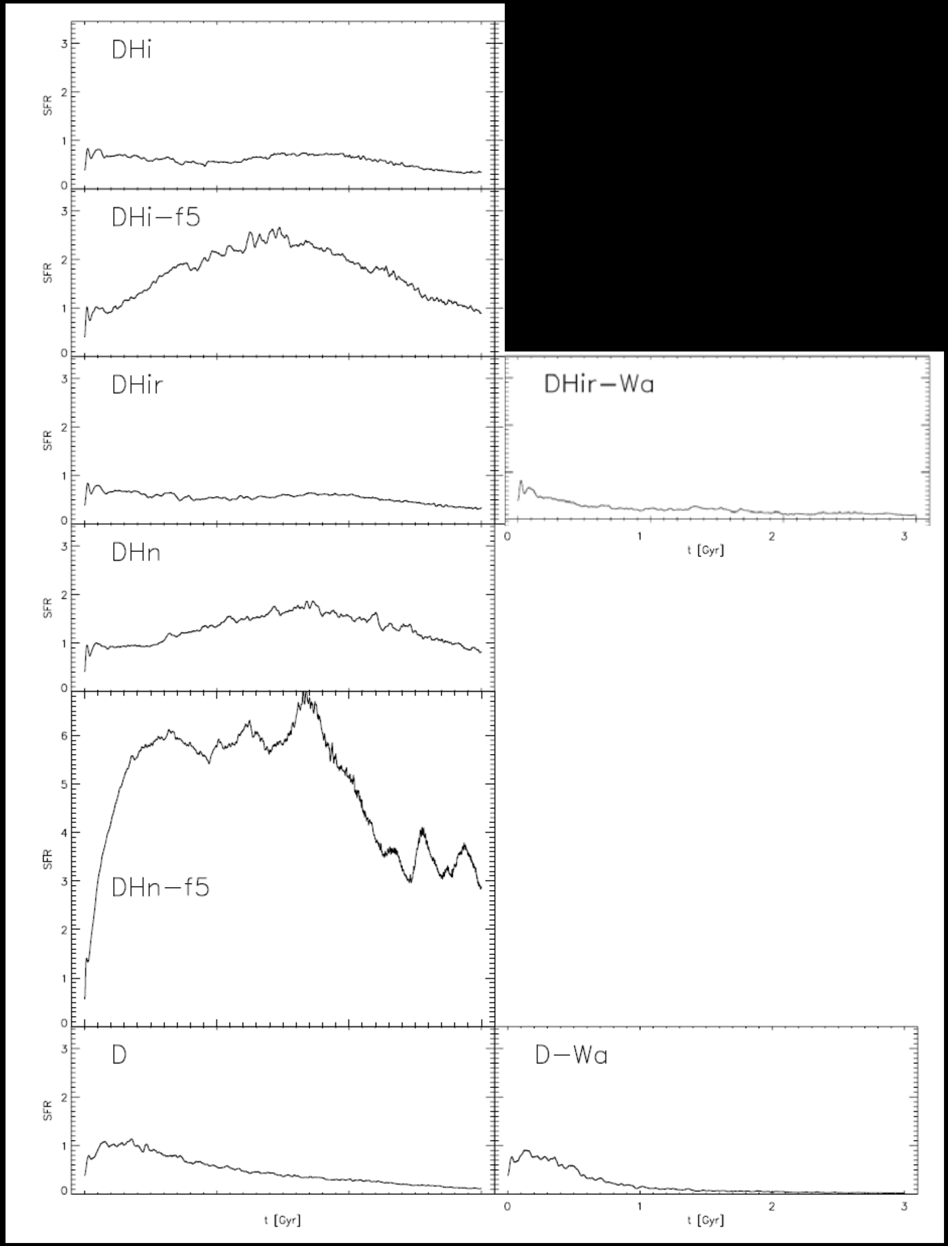


(Set 2) t=1 Gyr





Star Formation Rate vs Time



Summary

We find that the evolution of the models is strongly affected by the adopted gas halo component, particularly in the gas dissipation and the star formation activity in the disk.

Model D: shows an increasing star formation rate (SFR) at the beginning of the simulation and then a continuously decreasing rate to the end of the run at 3 Gyr.

Type DH models: (depending on the density profile and M_{hg})
SFRs come out to be either relatively flat or
increasing until the middle of the run then decreasing to the end.

The rotation of a gas halo is found to make SFR lower in the model.

Galactic winds always make SFRs lower than the same runs but without winds.

Conclusion

We conclude that the effects of a gaseous halo on the evolution of galaxies are generally too significant to be simply ignored and expect that more hydrodynamical processes in galaxies could be understood through numerical simulations employing both gas disk and gas halo components.


감사합니다 :-)
Thank you!