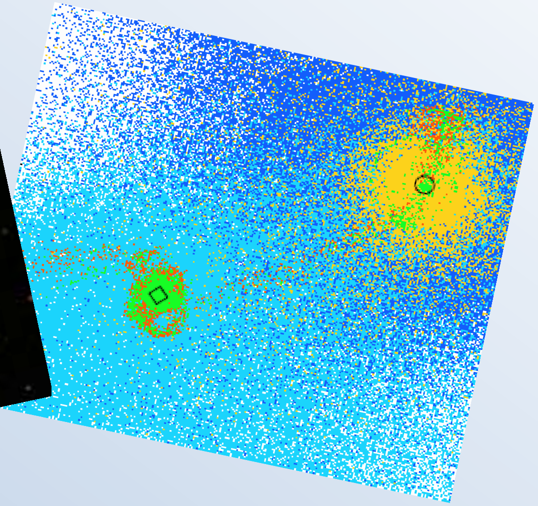
Studying Galaxy Interactions & Evolution using *N*-body/SPH Simulations



Jeong-Sun Hwang

The 3rd Survey Science Group Workshop (at Muju Resort) 2014-02-10

Background

To understand galaxy evolution

- Galaxy interaction is an important driver of galaxy evolution

Galaxy-Galaxy interactions change galactic properties:

- Star formation rates (SFR) , Structures, Morphology, etc

Unveiling physical mechanisms responsible for the changes are difficult.

- Galaxies are complex:
  - Early-type (Ellipticals, S0) & Late-type (Spirals)
  - Dark-matter, Stars, Gas, etc
- Interactions are diverse:
  - Major/Minor merger
  - Flyby encounters (occurring more frequently)
  - Processes over a wide range of spatial- & time-scales

→ Numerical modeling is an excellent way to solve the problem.

Background

In investigating the evolution of interacting galaxy systems, observations & numerical simulations are complementary:

- High-resolution observations provide:
  - physical quantities & information
  - model constraints

- Numerical simulations provide:
  - direct experiments & analyses via simulated media
  - interpretation of observational results
  - additional constraints & information (e.g. DM halo profiles)

Motivation

Spiral galaxies comprise five different components:

DM halo, stellar disk, stellar bulge, gaseous disk & ***gaseous halo***

So far, *however,*

ICs for almost all hydrodynamic simulations of galaxy interactions have considered ***only cold gas.***

→ We take ***both gas components*** into account in our ICs.

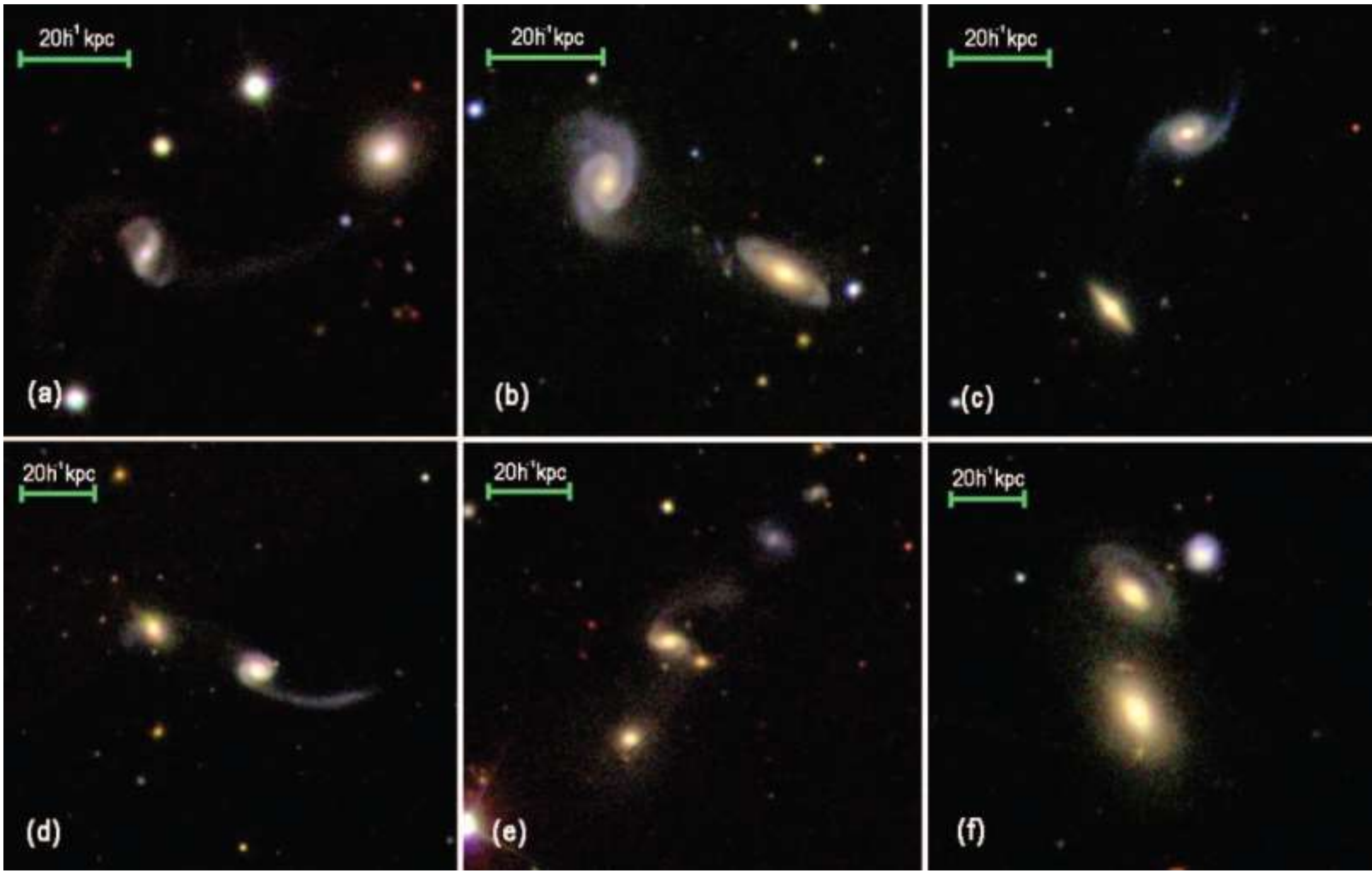
Park, Gott, & Choi, 2008:

"Transformation of Morphology & Luminosity Classes of the SDSS Galaxies"

→ Galaxy's morphology critically depends on the nearest neighbor (as well as on luminosity & the large-scale density).

Park, Gott, & Choi 2008

Evolution of Morphology



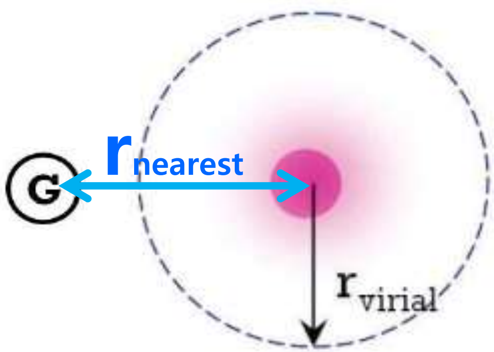
Park, Gott, & Choi 2008

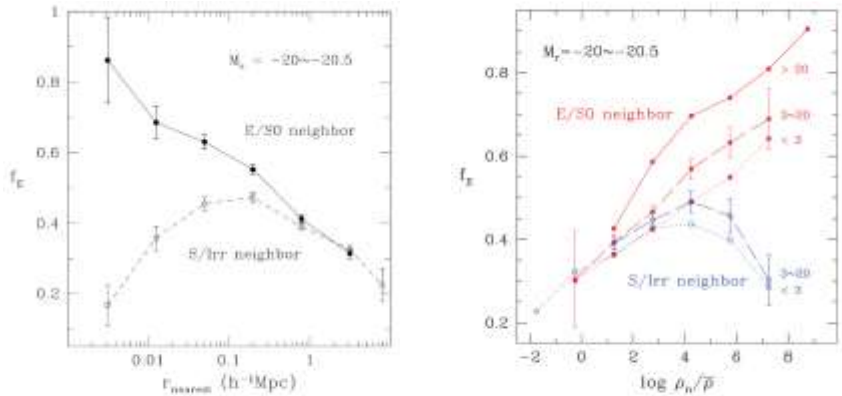
Evolution of Morphology

f_E = Probability for a (target) galaxy to be an early-type

$r_{nearest}$ = distance between a target galaxy & its nearest neighbor

data sample: $M_r < -19.5$ $0.025 < z < 0.08588$ $74.6 < R < 252.9$ 74,688





- $r_{nearest}$ > r_{virial} :
  - as $r_{nearest}$ ↓ , f_E ↑
  - galaxy morphology is independent of the neighbor's morphology
  - due to the tide exerted by the closest neighbor
- $r_{nearest}$ < r_{virial} :
  - with an early-type neighbor: as $r_{nearest}$ ↓, f_E ↑
    due to the tidal effects + hydrodynamical effects of hot gas of the neighbor
  - with an late-type neighbor: as $r_{nearest}$ ↓, f_E ↓
    due to the cold gas flowing from the neighbor

Our Numerical Study

The primary focus:

To find the effects of a hot gaseous halo on galaxy evolution

Our first sets of simulations (Hwang, Park, & Choi, 2013, JKAS, 46, 1):

"The ICs and Evolution of Isolated Galaxy Models: Effects of the Hot Gas Halo",

the first in series of planned papers

On-going work:

- Interactions between ETG & LTG and morphology transformation" (d~50kpc)
- Effects of hot halo gas on the SFR during distant ETG-LTG encounters" (d~100kpc)
- Fast flyby interactions between ETG & LTG (cluster environment)
- (Planed) Relation between bar strength & $r_{nearest}$

Recently,

a comprehensive set of numerical convergence tests have been completed

- to find optimal values for simulation parameters
- to minimize numerical errors at reasonable computation time

Numerical Codes

ZENO software package

- To generate initial galaxy models (ICs)
- Allows one to build multiple components in mutual equilibrium with user-specified density profiles in collisionless or gaseous form.
- Developed by Joshua Barnes

Gagdet3 simulation code

- To evolve the galaxy models
- *N*-body/SPH (Smoothed Particle Hydrodynamics) code
- Implemented physics:

  Radiative cooling, Star formation, SN feedback,

  Sub-resolution model of multiphase ISM (Springel & Hernquist 2003)
- Provided by Volker Springel

Gadget
(GAlaxies with Dark matter & Gas intEracT)

Radiative cooling:

- Compute cooling function for a gas of primordial composition (H, He) (Katz et al. 1996; Springel & Hernquist 2003)
- The abundances of the various ionization states of H and He, assuming ionization equilibrium in the presence of an external UV background field (Haardt & Madau 1996)

Star formation:

- Conditions: $\nabla \cdot v < 0$

  $\rho_{gas} > \rho_{th}$

  Jeans unstable ($\tau_{sound} = h/c_s > \tau_{dyn} = 1/\sqrt{(4\pi G\rho)}$)

  $T < T_{th}$
- SFR: $\dot{M}_{stars} = (1-\beta)\, M_{cold} / \tau_{stars}$
- τ_{stars} is chosen to match observation (Kennicutt 1998)

Hwang, Park, & Choi 2013

Our Galaxy Models

Galaxy models with or without a gas halo:

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	···

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

(120 + 5 + 1)

DM halo: NFW profile

Gas halo: Isothermal or NFW profile (f_{hg} = 0.01 or 0.05)

Stellar & Gas disks: Exponential profile (f_{dg} = 0.12)

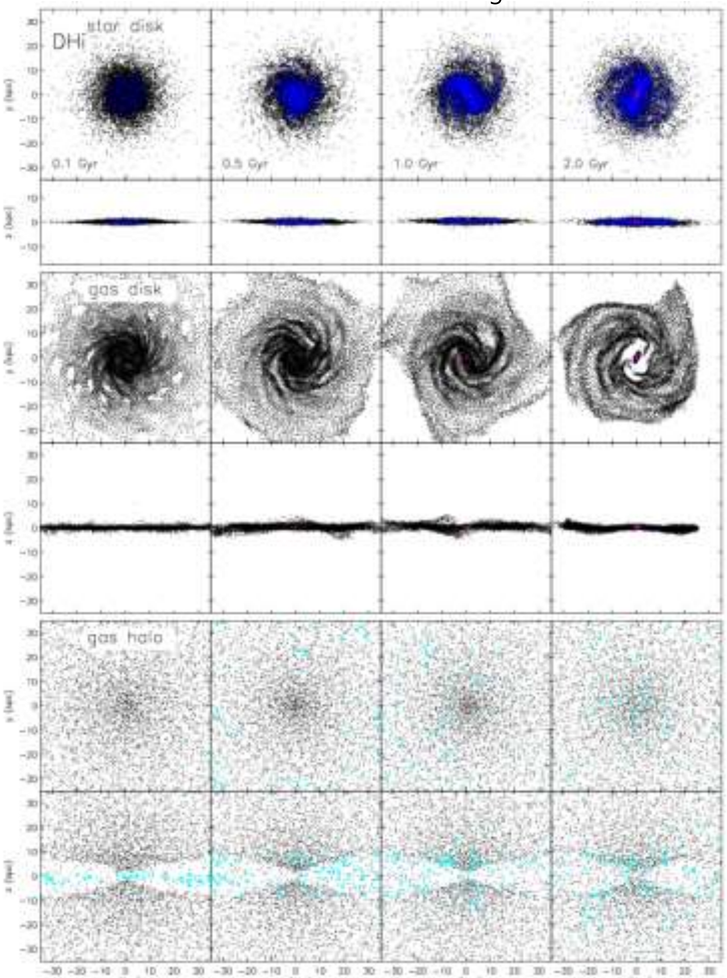
Stellar bulge: Hernquist profile

Hwang, Park, & Choi 2013

Evolution

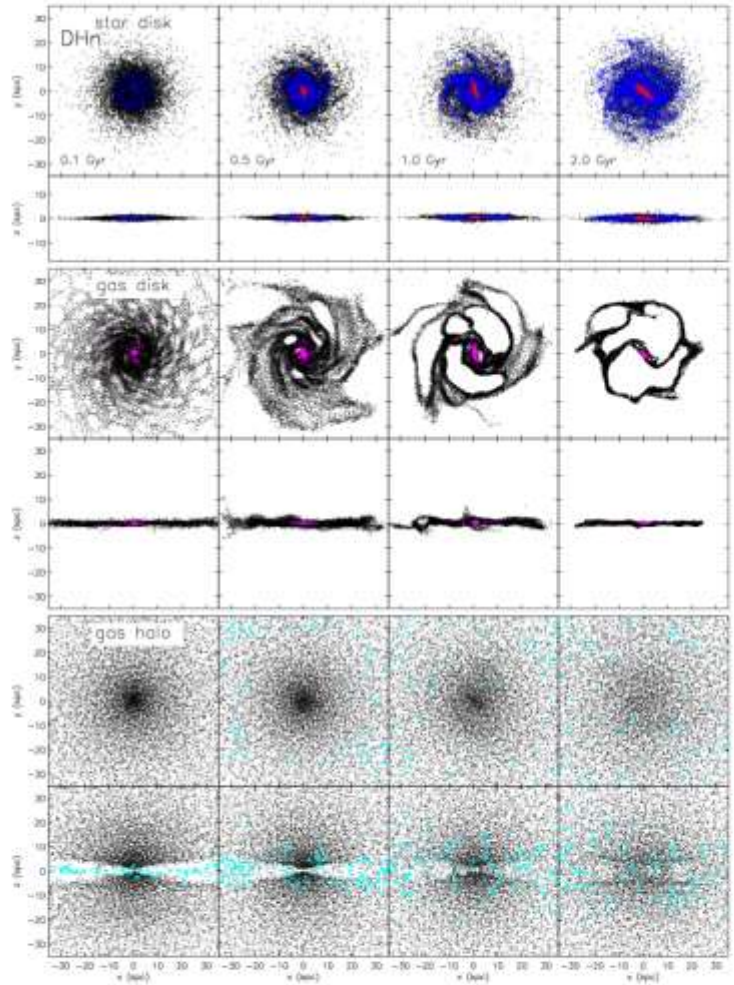
DHi

(isothermal gas halo, f_{hg} = 0.01)



DHn

(NFW gas halo, f_{hg} = 0.01)



Hwang, Park, & Choi 2013

Results

Evolution of the models is strongly affected by the adopted gas halo component particularly in the gas dissipation & the star formation activity in the disk.

Model with a gas halo show higher SFRs than those without a gas halo (due to gas accretion from the halo onto the disk).
Models with the NFW gas halo show higher SFRs than those with the isothermal gas halo.

The rotation of a gas halo makes SFR lower. (shock heating & angular momentum barrier)

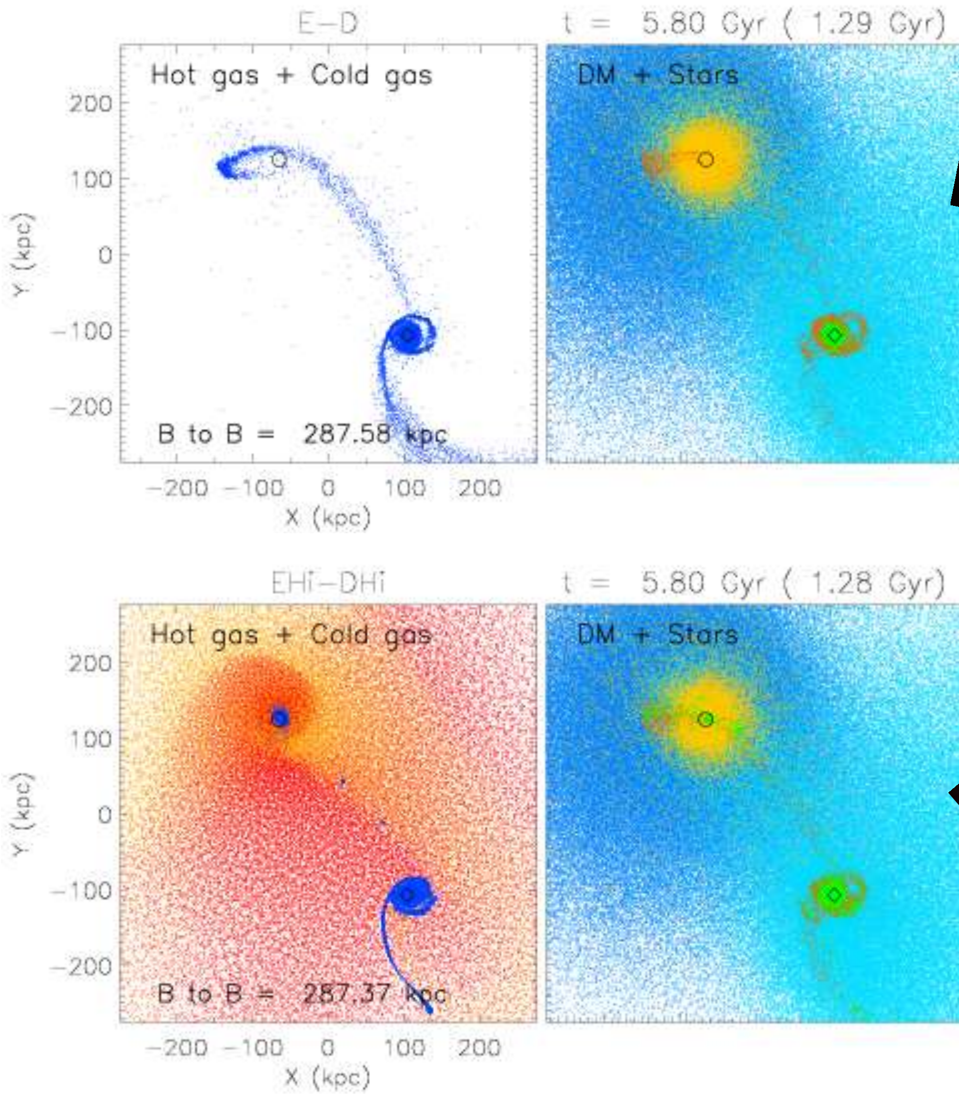
We expect that more hydrodynamical processes in galaxies could be understood through numerical simulations employing both gas disk & gas halo components.

Ongoing work
d~50kpc

ETG-LTG Interactions

E-D →
(w/o gas haloes)

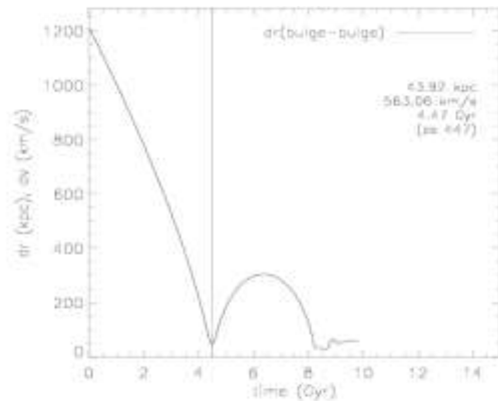
EHi-DHi →
(with gas haloes)



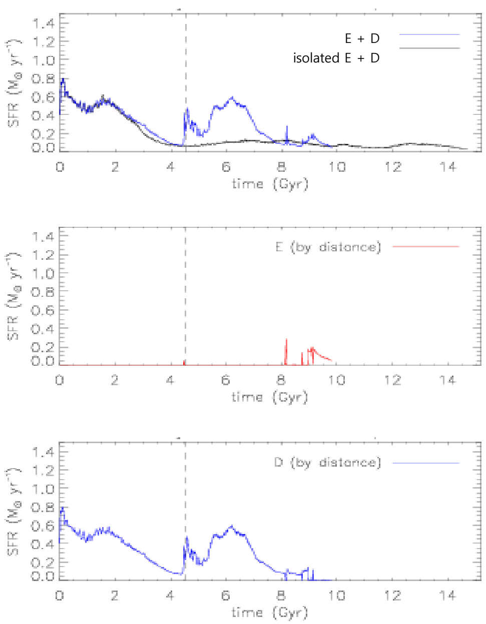
Ongoing work
d~50kpc

Star Formation Rates

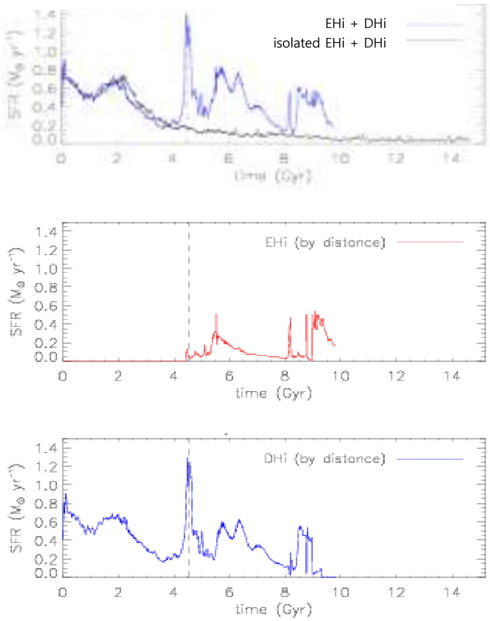
ETG-LTG, d50



E-D



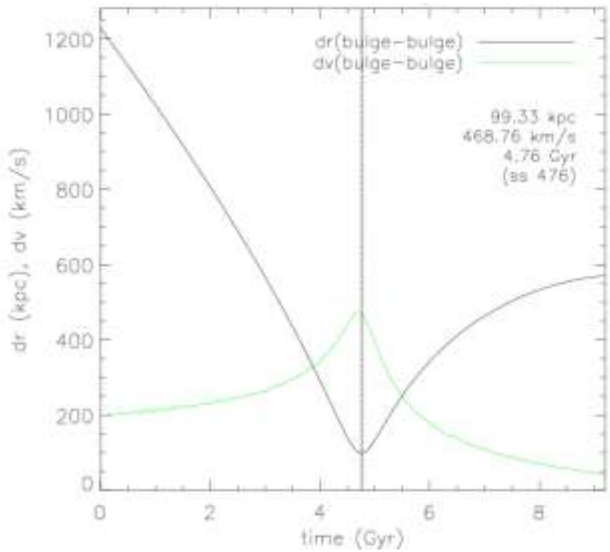
EHi-DHi



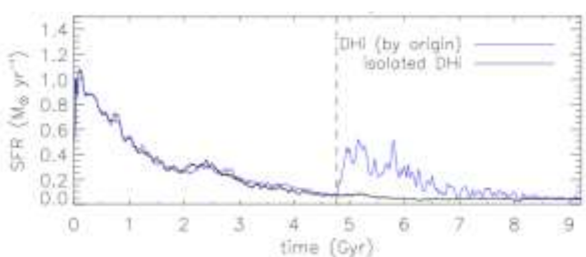
Ongoing work
d~100kpc

Star Formation Rates

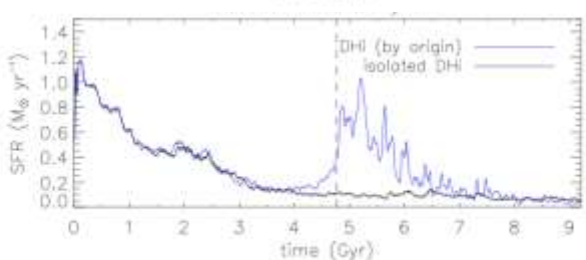
ETG-LTG, d100



E-D

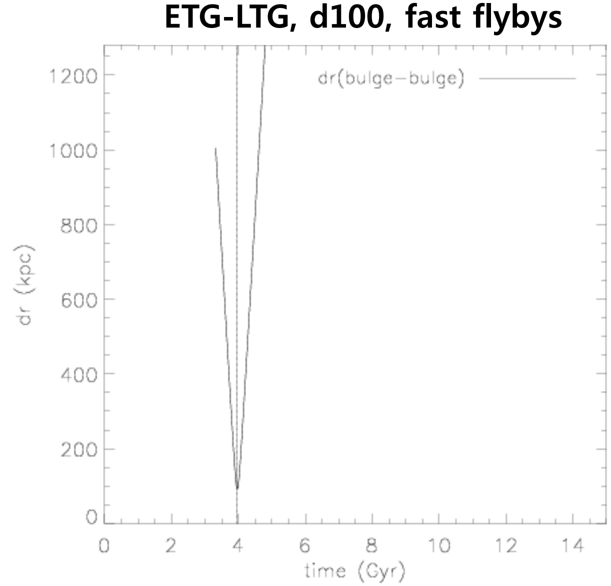


EHi-DHi

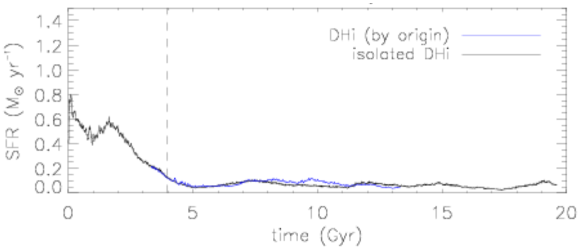


Ongoing work
d~100kpc

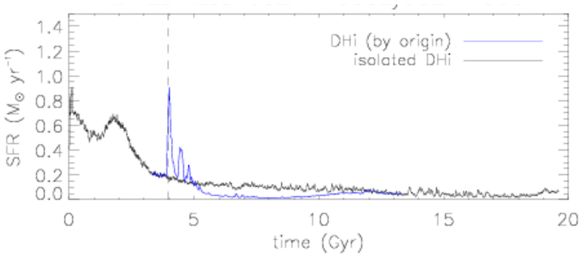
Star Formation Rates



E-D



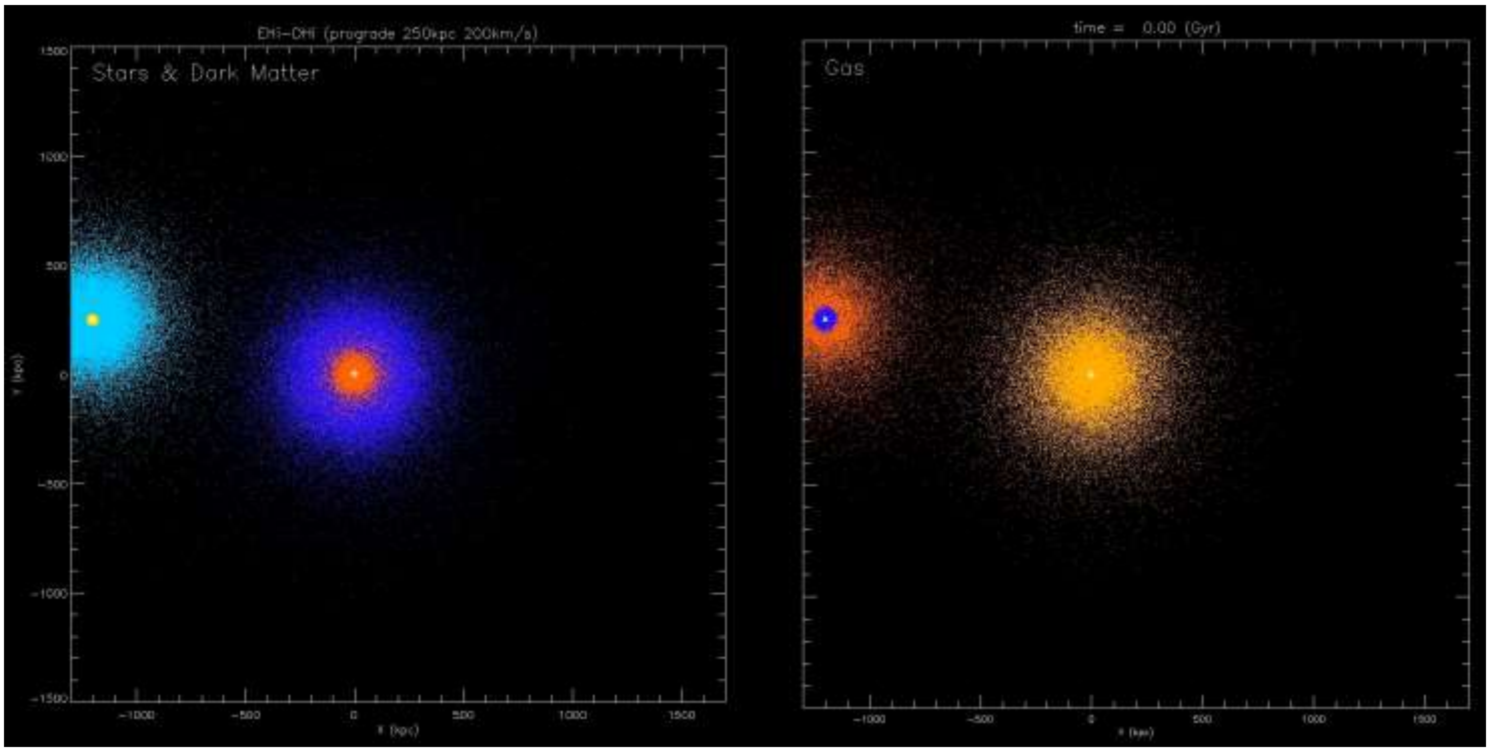
EHi-DHi



EHi-DHi, d~100kpc

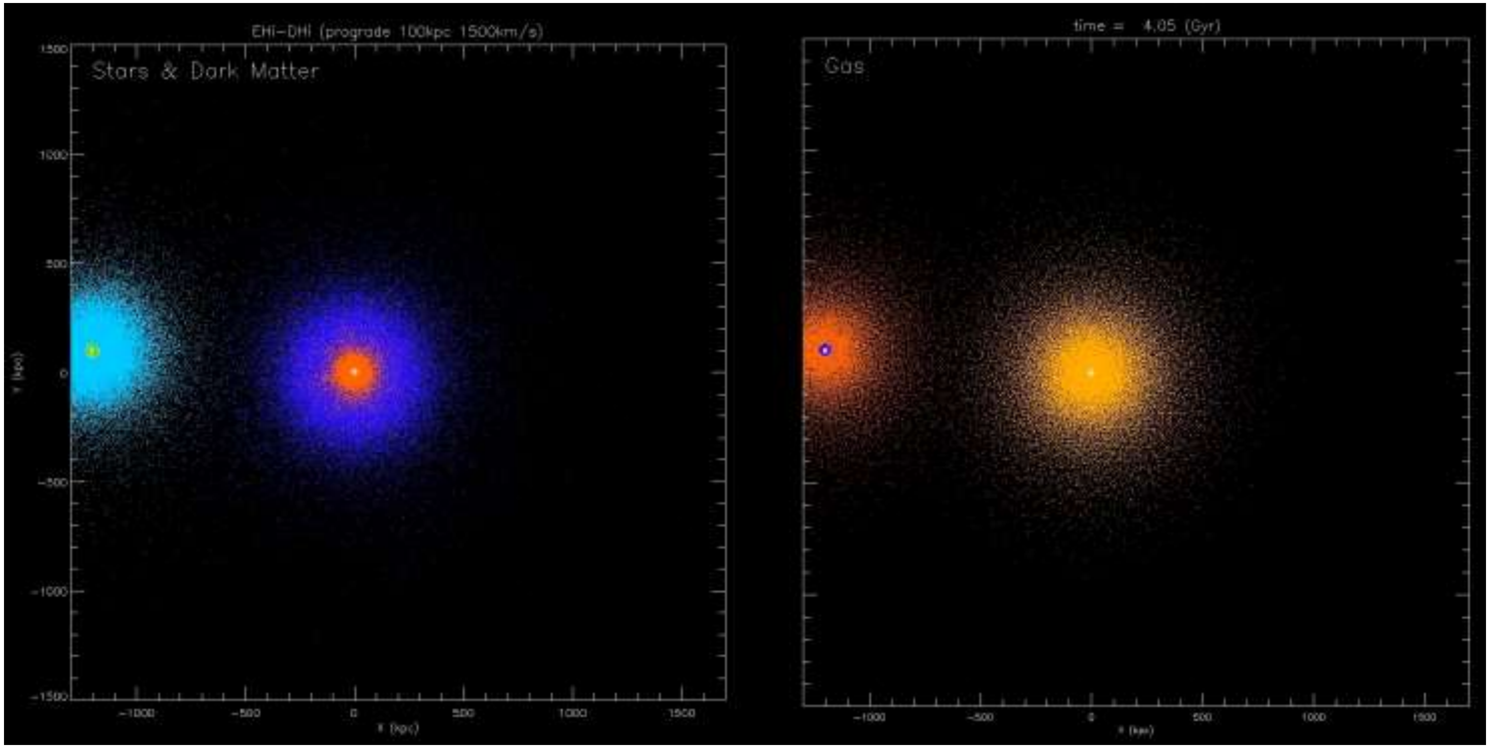
DM + Stars

Hot & Cold gas



EHi-DHi, d~100kpc, fast flyby

DM + Stars　　　　Hot & Cold gas



Thank you :-D