Effects of periodic supernova feedbacks on the formation of UDGs and the cusp-to-core transformation in CDM halos

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Outline

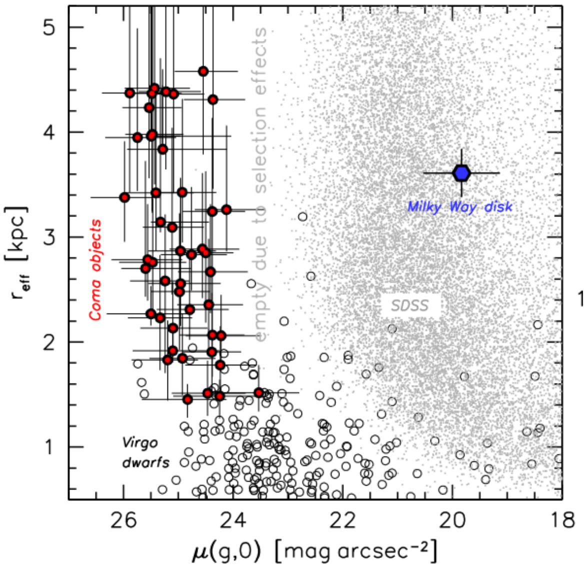
Introduction

Ultra-diffuse galaxy (UDG)

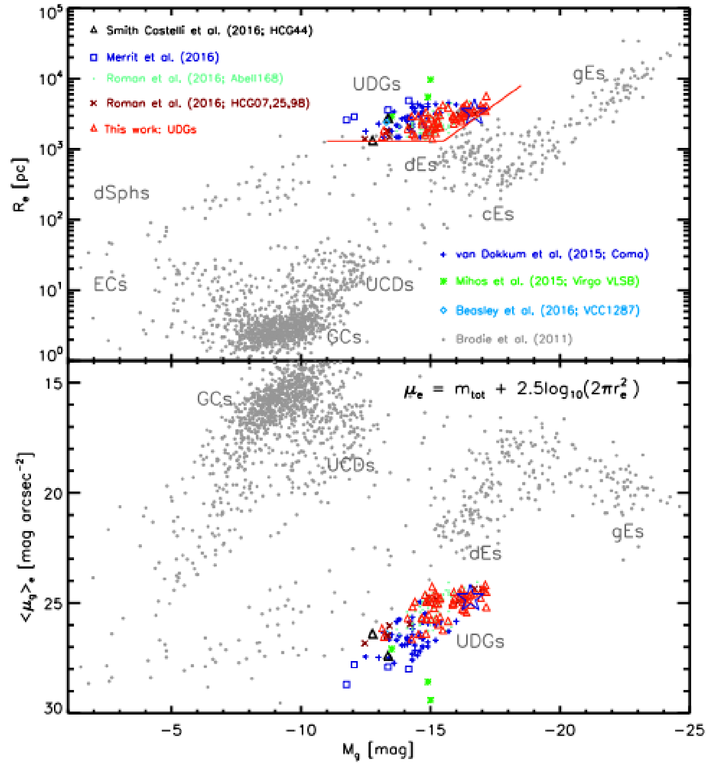
van Dokkum et al. (2015) discovered new galaxy population in the COMA cluster.

UDG: r_{eff} > 1.5 kpc and

$<\mu>$ > 24 mag/arcsec^2 .



van Dokkum et al. (2015)



Dong Dong Shi et al. 2017

Typical physical quantitiy of UDG

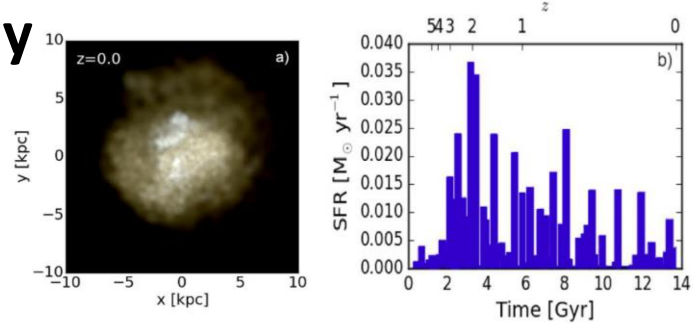
Most of UDGs are found in the dense regions such as galaxy clusters and galaxy groups. A few UDGs are detected in low dense regions in the local universe.

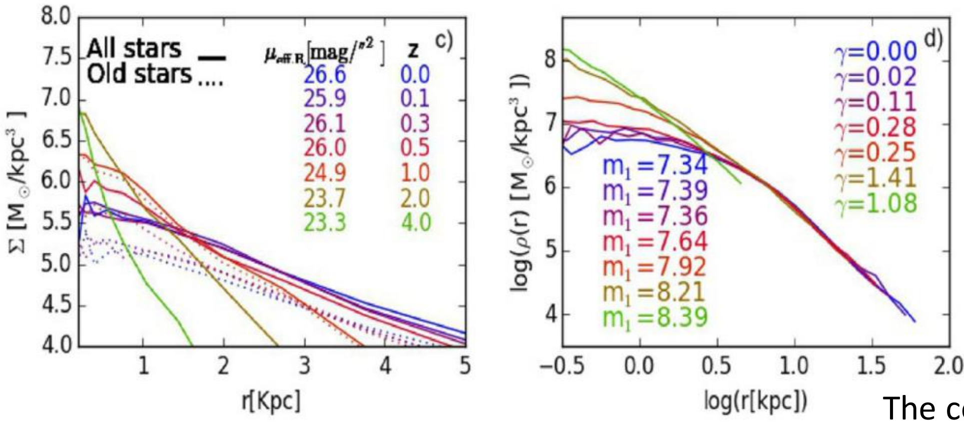
Physical quantity	Quantity	Reference
Total dynamical mass	$10^{10} \sim 10^{11} M_\odot$	Lee et al. 2017[54]; Amorisco et al. 2018[2]; Sifón et al. 2018[95]
Total stellar mass	$10^{7} \sim 5 \times 10^{8} M_\odot$	Koda et al. 2015[52]; Leisman et al. 2017[55]; Shi et al.2017[94]; Sifón et al. 2018[95]
Average half-light radius	$2 \sim 3$ kpc	Lee et al. 2017[54]; Sifón et al. 2018[95]
HI gas mass in cluster UDGs	Almost none	Koda et al. 2015[52]; Toloba et al. 2018[108]
HI gas mass in field UDGs	$10^{8} \sim 5 \times 10^{9} M_\odot$	Leisman et al. 2017[55]; Shi et al.2017[94]; Spekkens K. & Karunakaran A. 2018[103]
Metallicity	$-1.5 <$[Z/H]< -0.5	Ferré-Mateu et al. 2018[32]; Gu et al. 2018[41]; Pandya et al. 2018[79]; Ruiz-Lara et al. 2018[90]
Age	$7 \sim 10$Gyr	Ferré-Mateu et al. 2018[32]; Gu et al. 2018[41]; Pandya et al. 2018[79]; Ruiz-Lara et al. 2018[90]
Average Sérsic index	~ 1.0	Koda et al. 2015[52]; Lee et al. 2017[54]

Previous theoretical study

NIHAO project
Arianna Di Cintio et al. 2017

UDG formation with
Cosmological simulation





The color indicates redshift.

・ Feedback-driven gas outflows, and subsequent dark matter and stellar expansion, are the key to reproduce low-surface galaxies.

・UDGs represent a dwarf population of low surface brightness galaxies and should exist in the field.

・The largest isolated UDGs should contain more HI gas than less extended dwarfs of similar mass.

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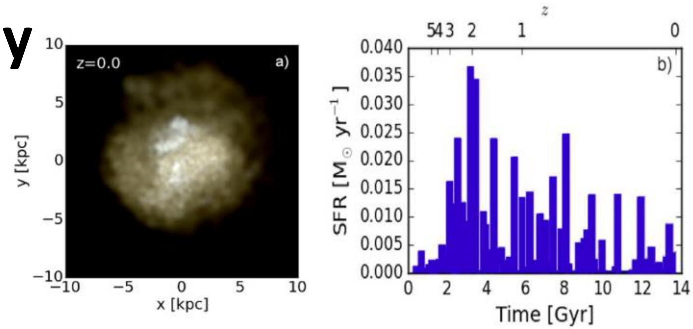
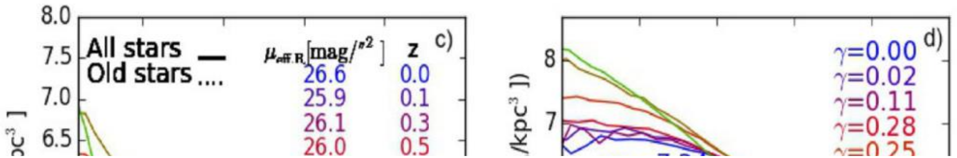
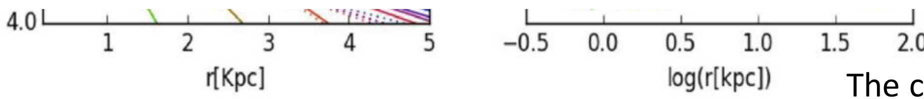




・ However, the key mechanism for forming of UDG is not understood.



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Aim

・ Investigate the physical mechanism of stellar system expansion in UDG formation.

・ To get insights about the bifurcation in the formation history of UDG and dE.

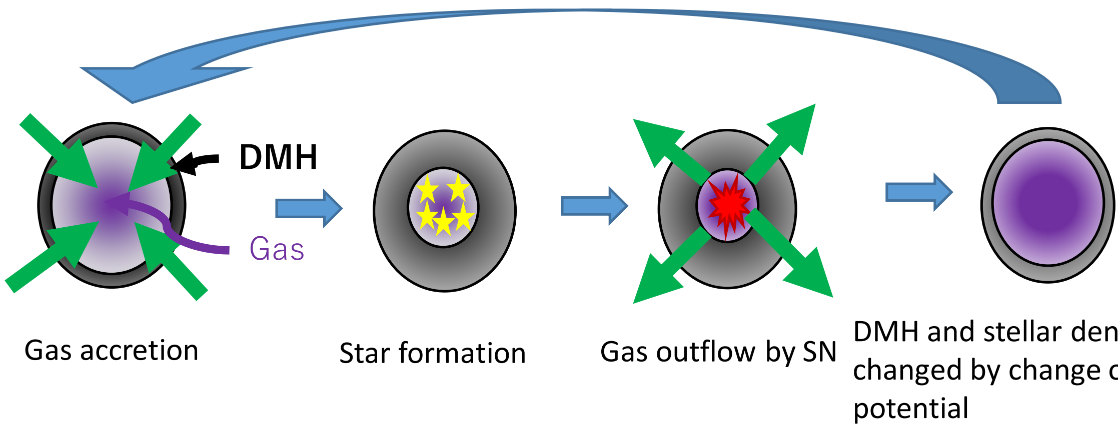
Method

Considered background process

We consider recursive gas inflow and outflow driven by supernova(SN) feedback. (e.g. Ogiya and Mori. 2014)

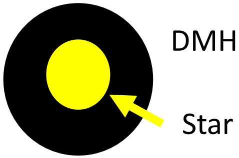
The galactic outflow driven by supernova feedback loses energy by radiative cooling, and then falls back toward the galactic center. Subsequently, the starburst is enhanced again. This cycle of expansion and contraction of the interstellar gas leads to a recursive change in the gravitational potential.

Physical process



Initial condition

・Generate an N-body system of DM and star with the same mass particles by MAGI (Miki and Umemura 2018).



Dark matter halo

N= $2^{24} \approx 10^7$ particles

$M_{\mathrm{DMH}} = 5 \times 10^{10} M_\odot$ Typical observed dynamical mass of UDG

NFW profile with cut off radius

$$\rho(r) = \frac{\rho_s r_s^3}{r(r_s + r)^2} \frac{1}{2} \mathrm{erfc}\left(\frac{r - r_c}{2\Delta_c}\right)$$

$r_s = 7.5\mathrm{kpc}$
$r_c = 37.5\mathrm{kpc}$
$\Delta_c = 3.75\mathrm{kpc}$

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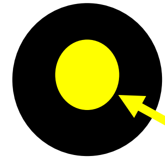

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Stellar system

$M_* = 1.0 \times 10^8 M_\odot$

Hernquist profile with cut off radius

$$\rho(r) = \frac{\rho_* r_*^3}{r(r_* + r)^3} \frac{1}{2} \mathrm{erfc}\left(\frac{r - r_{c*}}{2\Delta_{c*}}\right)$$

$r_{c*} = 7.5\mathrm{kpc}$
$\Delta_{c*} = 0.5\mathrm{kpc}$

$r_* = 0.55 r_{1/2}$

$r_{1/2} = 500\mathrm{pc}$ (adopted from the typical half-light radius of dE)

Periodic gas inflow and outflow

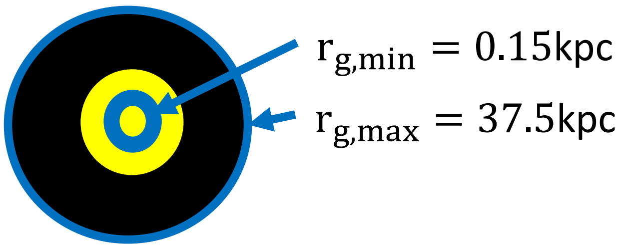
$$a(\boldsymbol{r}) = \frac{-GM_g}{(r + r_g(t))^2}\frac{\boldsymbol{r}}{r}$$ Hernquist profile

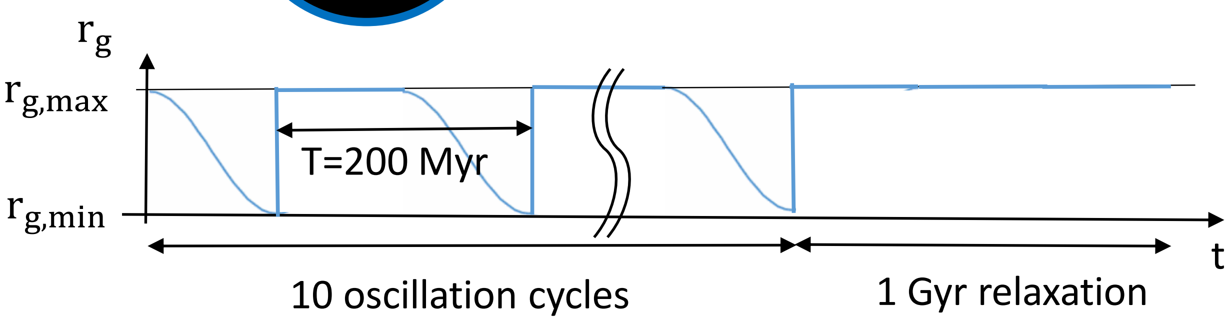
$M_g = 1.0 \times 10^8 M_\odot$ (Weak feedback)

$5.0 \times 10^8 M_\odot$ (Strong feedback)

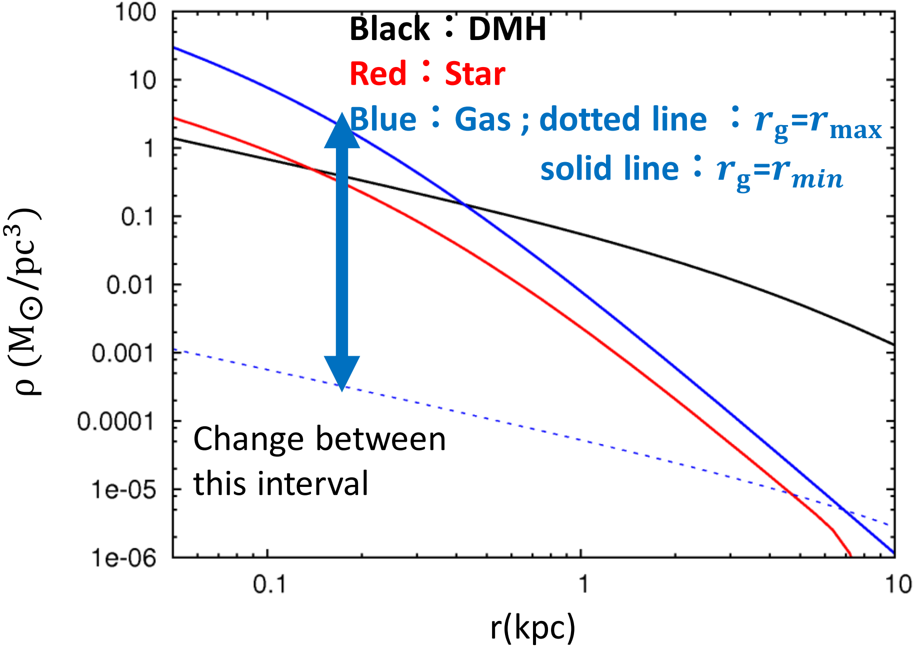
$r_g(t) = 0.5[r_{g,max} - r_{g,min}] \times [1 + \cos(2\pi\, t/T + \varphi_0)] + r_{g,min}$ for $(T \leqq 0.5)$

$r_g(t) = r_{g,max}$ for $(T > 0.5)$





Density profile of DMH, star and gas



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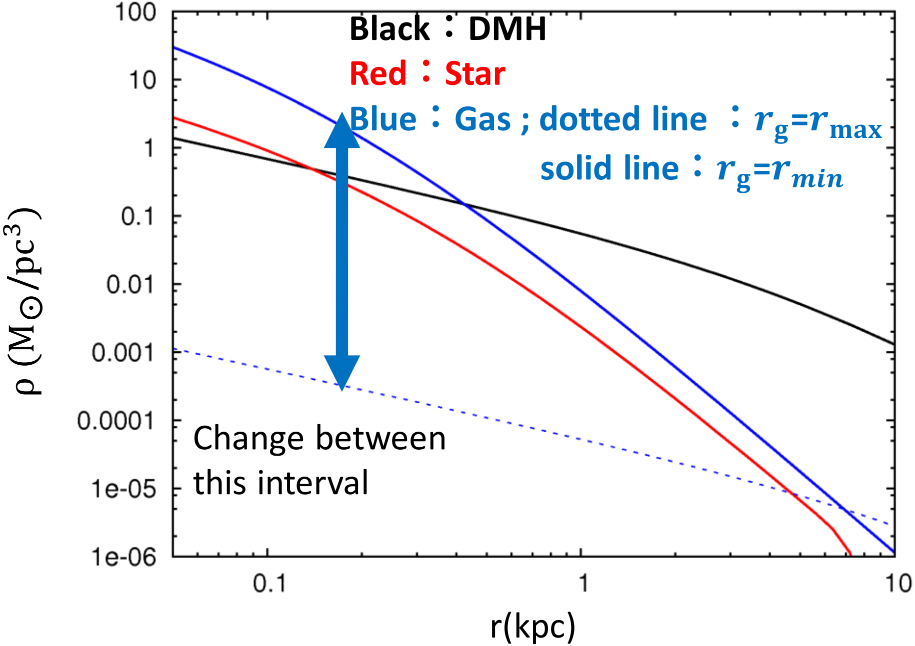


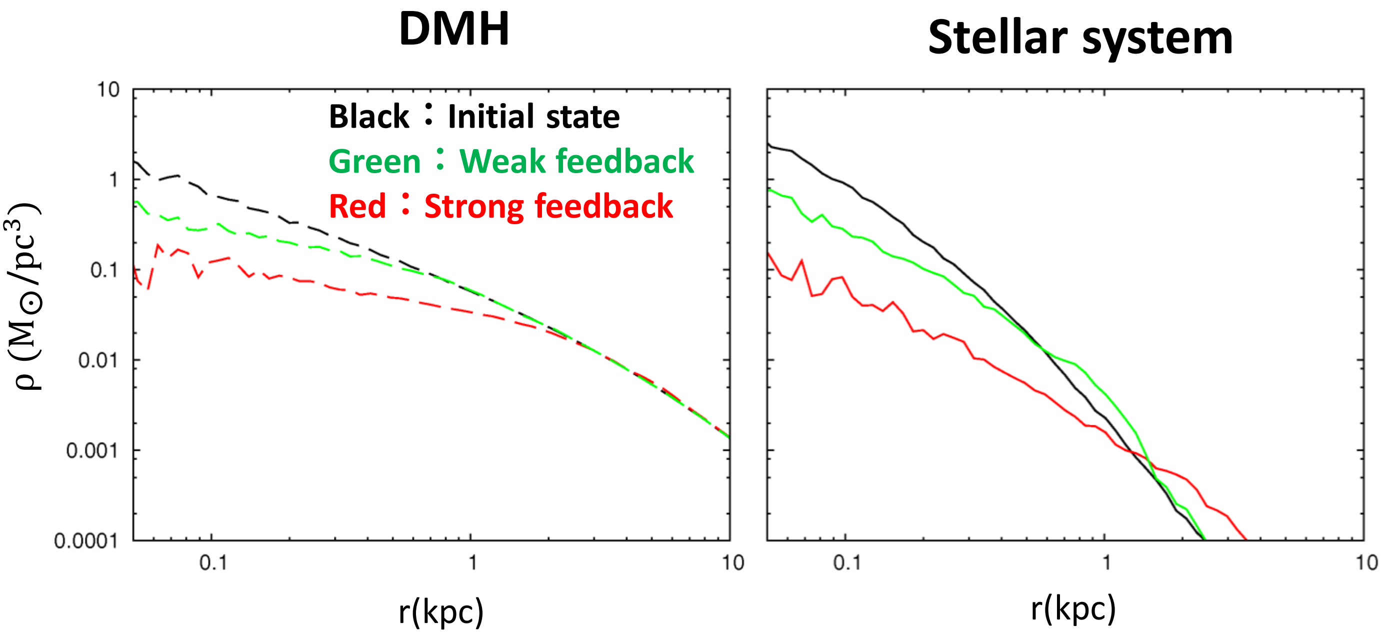
Numerical method:

Self-Consistent Field(SCF) method e.g. Clutton-Brock (1972,1973) , Hozumi (1997)

- computational costs ∝ N × (n_{max}+1) × (l_{max}+1) × (m_{max}+1) ;
  N:Number of particles , n_{max} , l_{max} , m_{max} : number of expansion terms
- free from the gravitational softening

Result

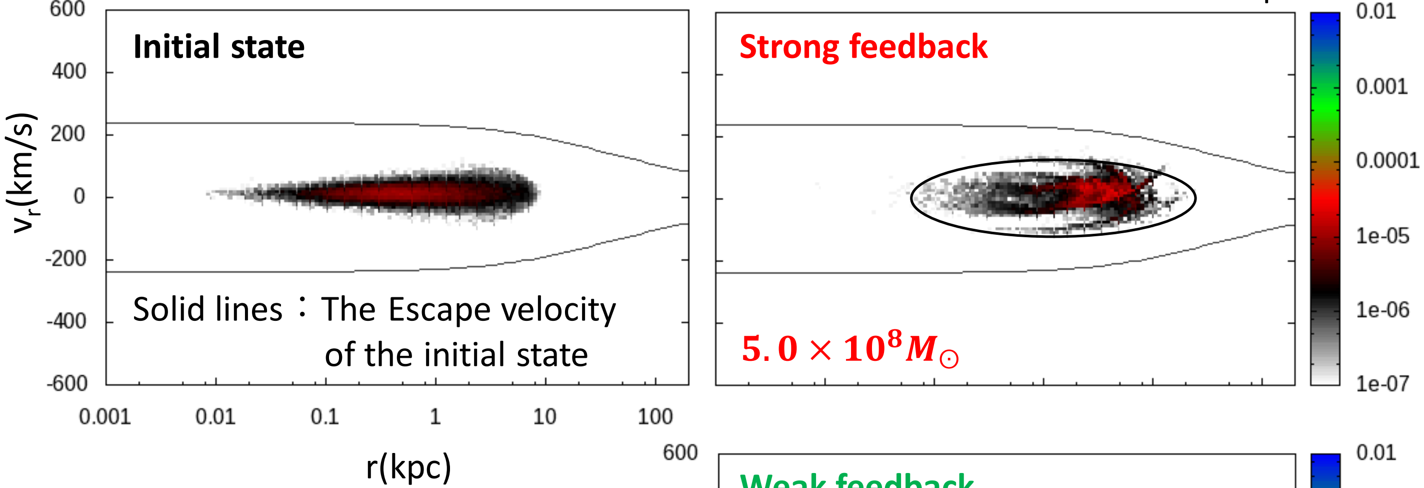
Density profile



・ In the case of strong feedback, the stellar system expands due to the gain of kinetic energy through the periodic change of gravitational potential driven by stellar feedback.

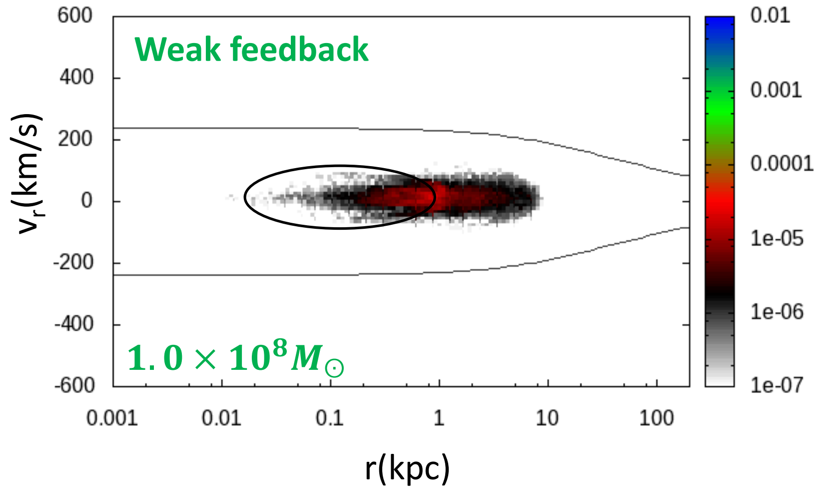
Phase space density of the stellar system

Color bar: Fraction of particles



・The whole of the stellar system fluctuates greatly.

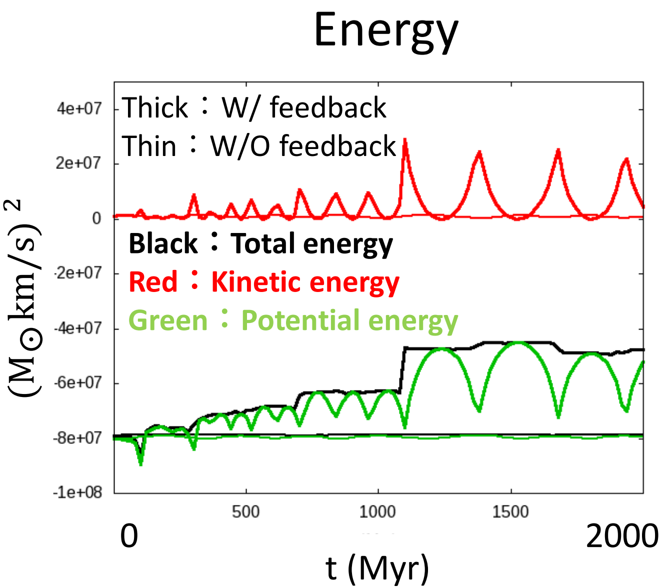
->A lot of star particles gain energy.

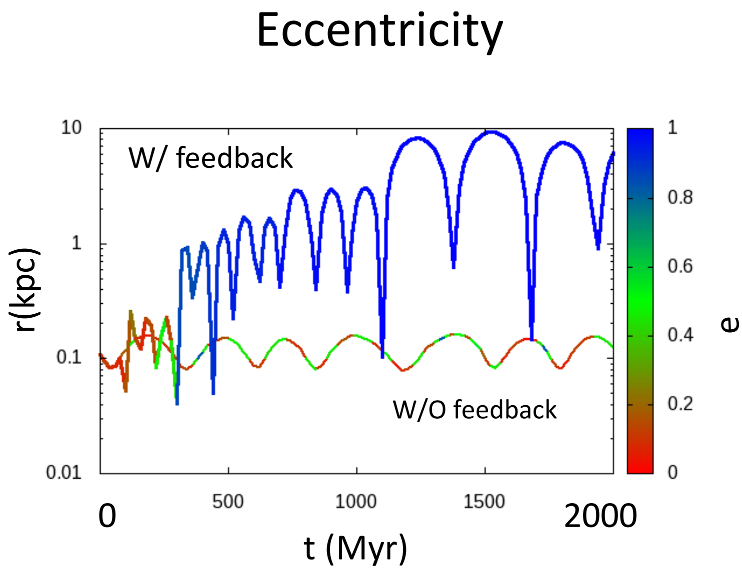


Dynamics of the stellar system

Time evolution of a particle

Strong feedback





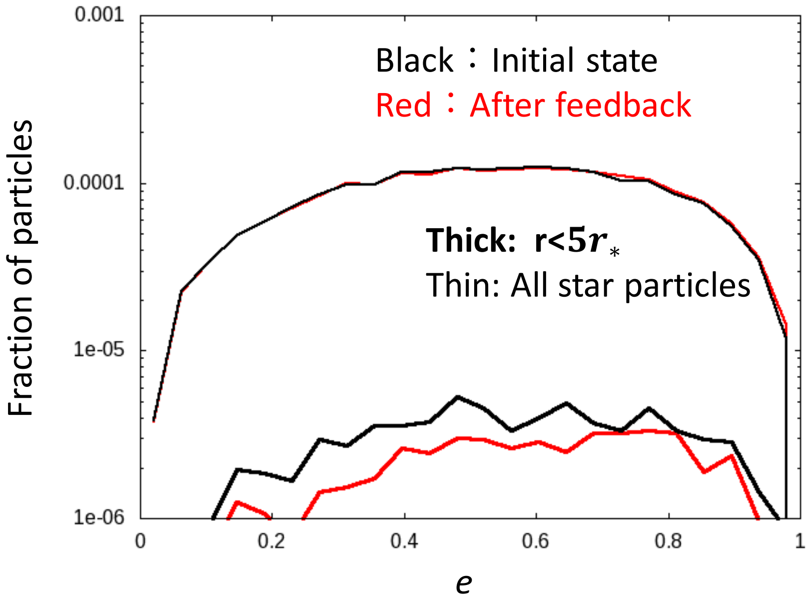
・A star particle gains the energy by the effect of the feedback.

・And then the eccentricity becomes large.

->The star particle moves to the outer region.

Eccentricity distributions

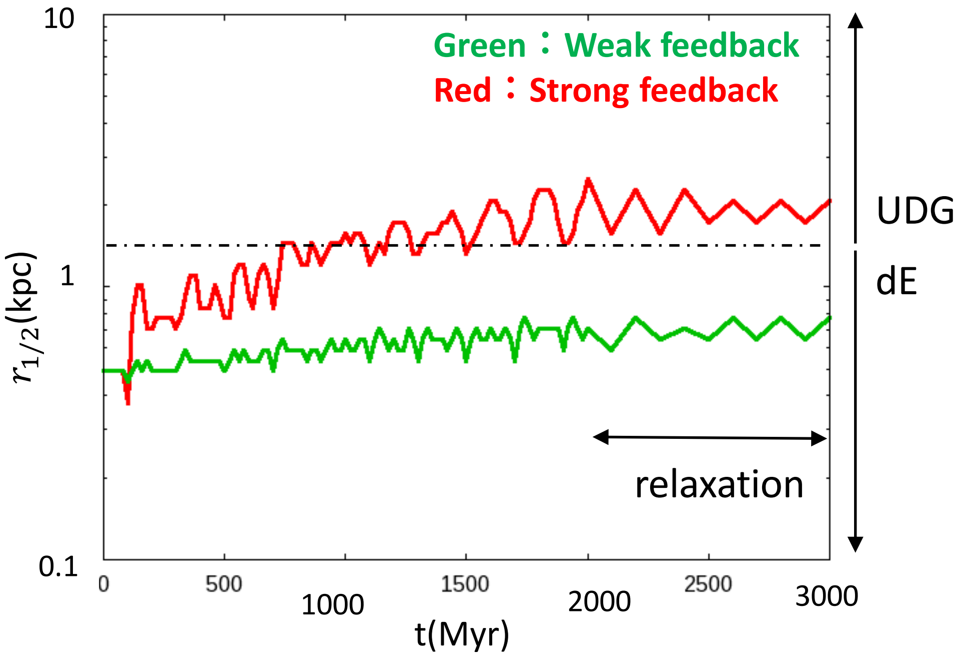
Strong feedback



・After feedback, number of low eccentricity particles decrease at the inner region.
->The stellar system expands.

Discussion

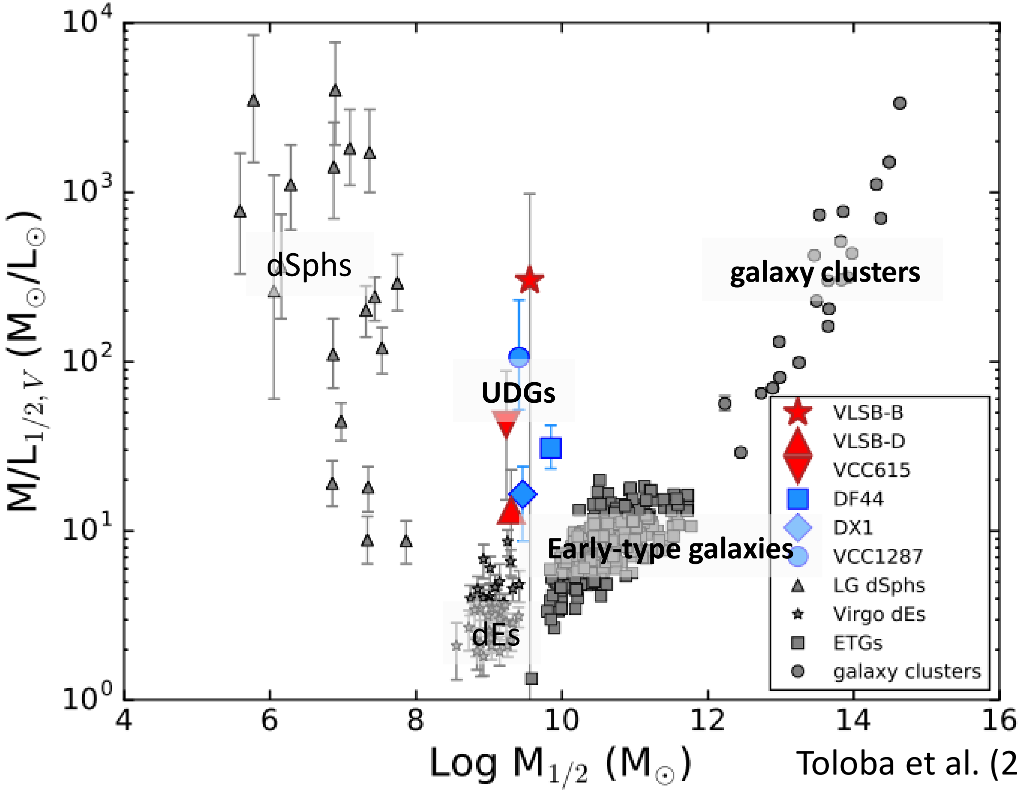
Half-mass radius



・In the case of strong feedback, the half-mass radius matched the observed half-light radius of UDG(>1.5kpc) assuming constant mass-to-light ratio $M_{\odot}/L_{\odot}$ =1 for star particles.

Comparison of observational quantity

Comparison with the result of Toloba et al. (2018)



Toloba et al. (2018)

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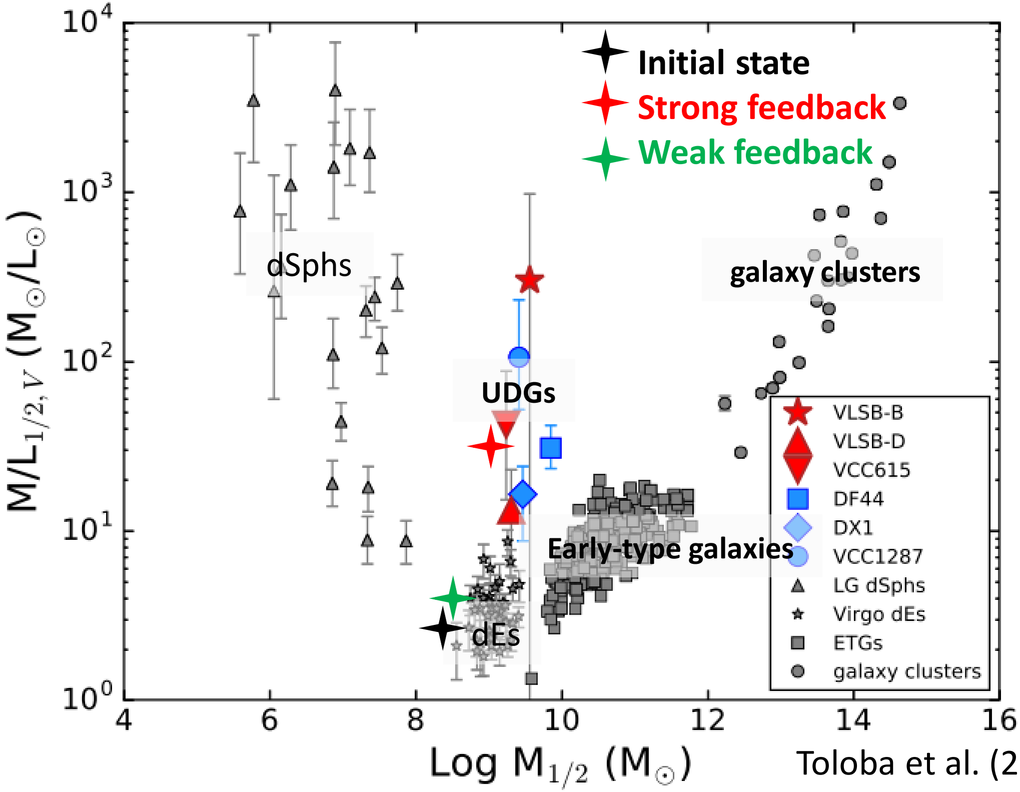

Toloba et al. (2018)

- In the case of strong feedback, our results reproduce the observed dynamical mass to stellar light ratio within the half-light radius in UDGs.
- In the case of weak feedback, it accounts for the dEs.

Summary

・Using the SCF simulation, we investigated the effect of the periodic stellar feedback on the formation of UDGs.

・ Our results indicate that periodic supernova feedbacks play an important role in the formation of UDGs.
The stellar system expands due to the gain of kinetic energy through the feedbacks.

・we successfully reproduced the typical observed features such as the half-light radius and the mass-to-light ratio in UDGs.

・ We found that the feedback strength relate to the final size of the half-mass radius of the stellar components.
This result indicates some insights into the bifurcation scenario on the formation of the dwarf elliptical galaxies and UDGs.