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DISSERTATION DEFENSE

Spiral Arms In Gaseous Galactic Discs Driven By Different Mechanisms

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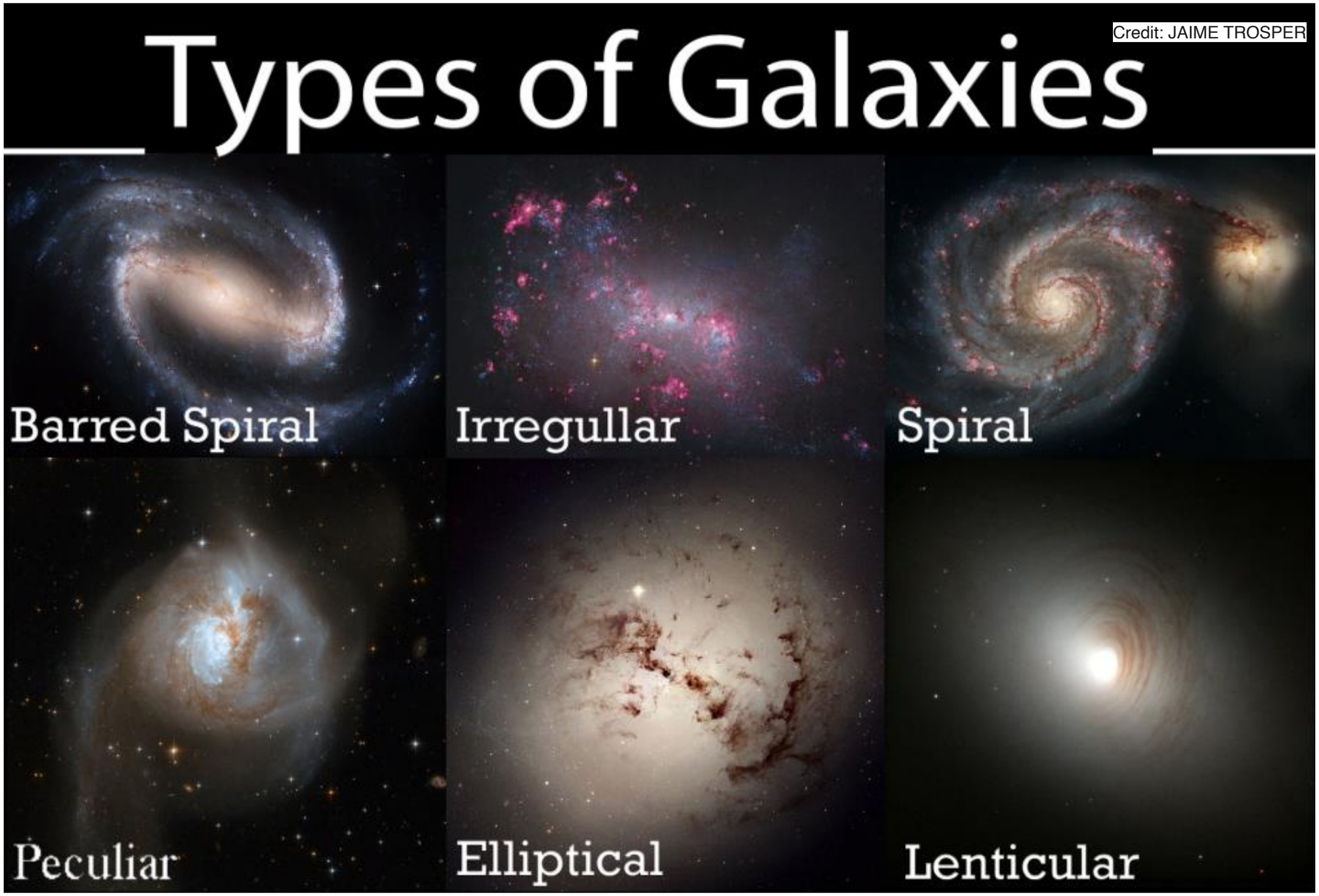
Advisor: Dr. Alex Pettitt

Aug 26th 2020

Introduction



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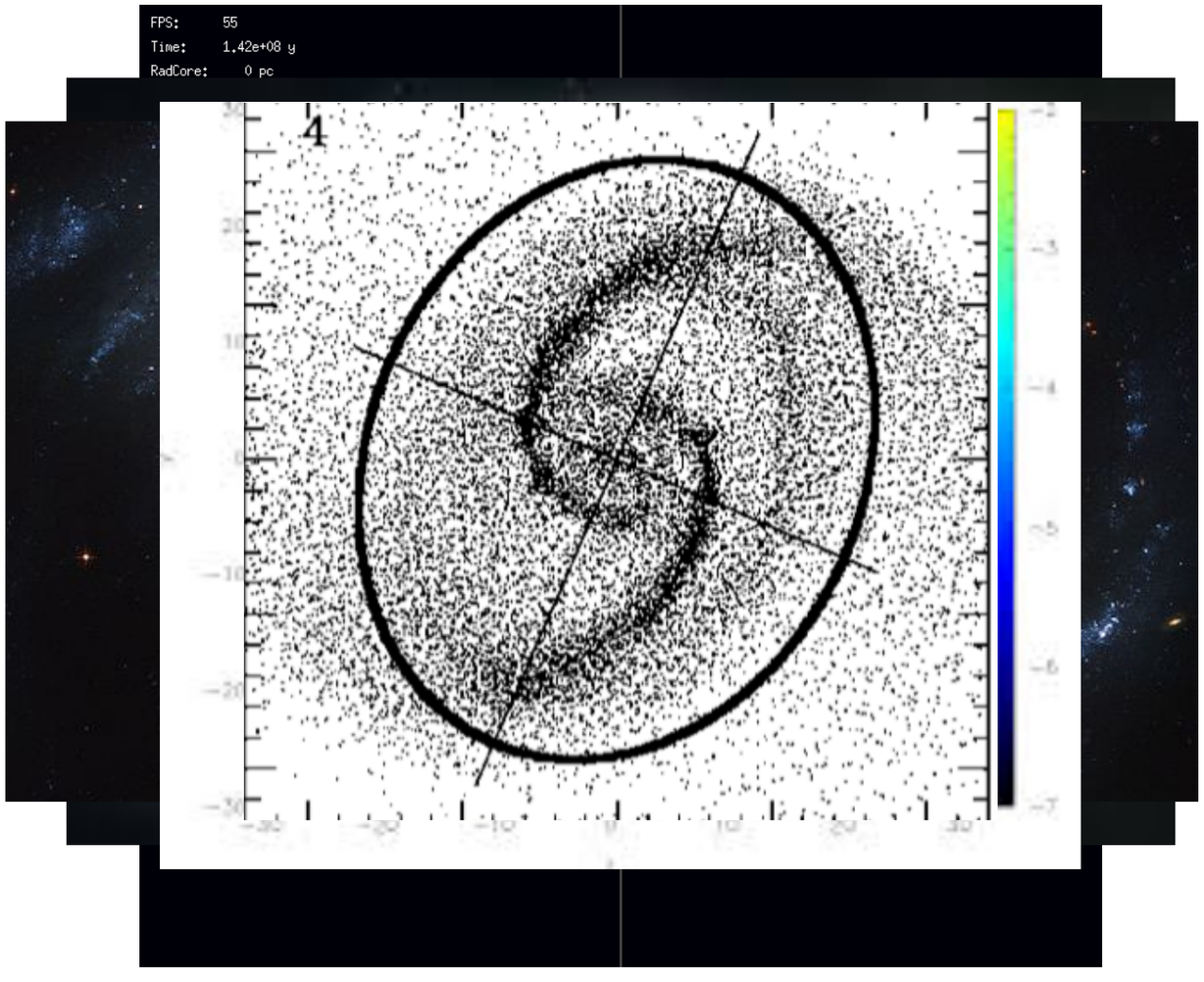
Origin of spirals



- **Density wave theory** (Lin & Shu, 1964)
- **Tidal interaction** (Toomre & Toomre, 1972)
- **Bar-driven galaxies**
  (Elmegreen & Elmegreen, 1982)
- **Self-gravity instabilities**
  (Sellwood & Carlberg, 1984)
- **Dark matter halos**

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Photos credits: beltoforion, wikipedia, Cossins et al. (2009) Khoperskov et al. (2011)

Thesis Aim

- **Triaxial dark matter halo role on galactic gaseous disc still remains as a puzzle.**

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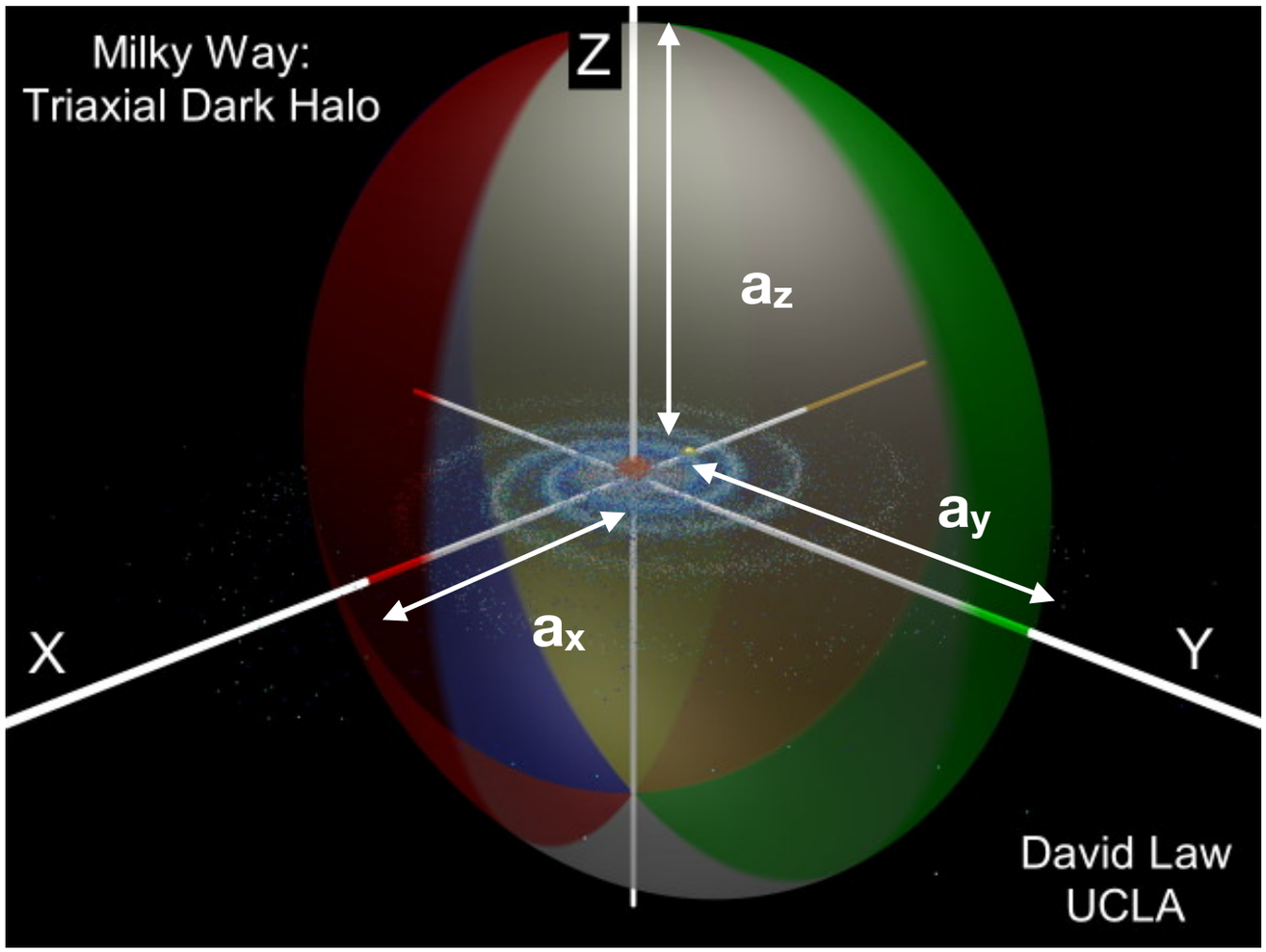
Previous Studies

Lorenzo P & and Amina H(2018)

Triaxial Dark Matter Halo



Triaxiality $=1 - a_y/a_x$

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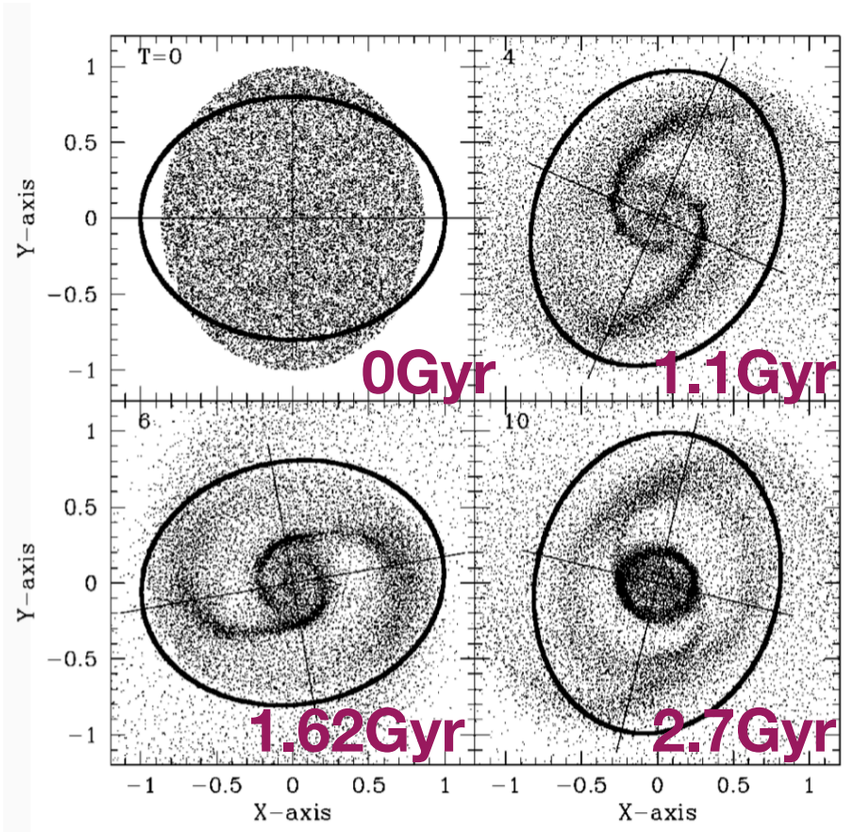
Previous studies



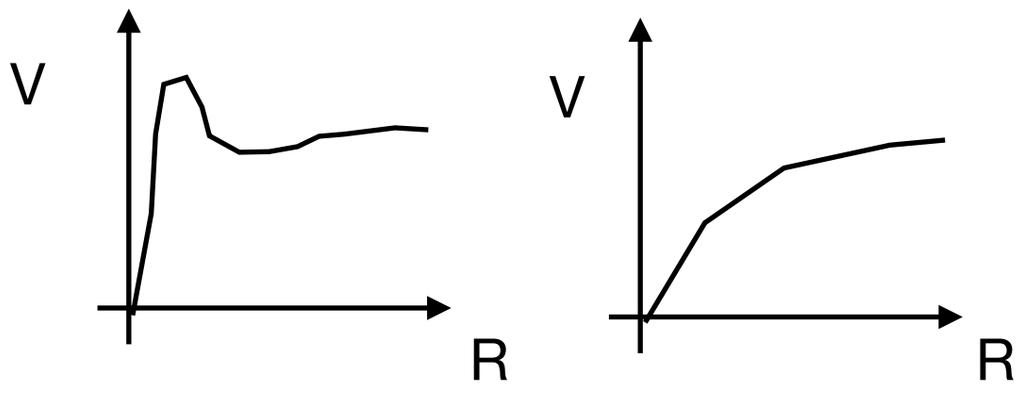
(Bekki K. & Freeman K.C. 2002)

Low resolution gas disc N ~ 10^4

Bad initial condition

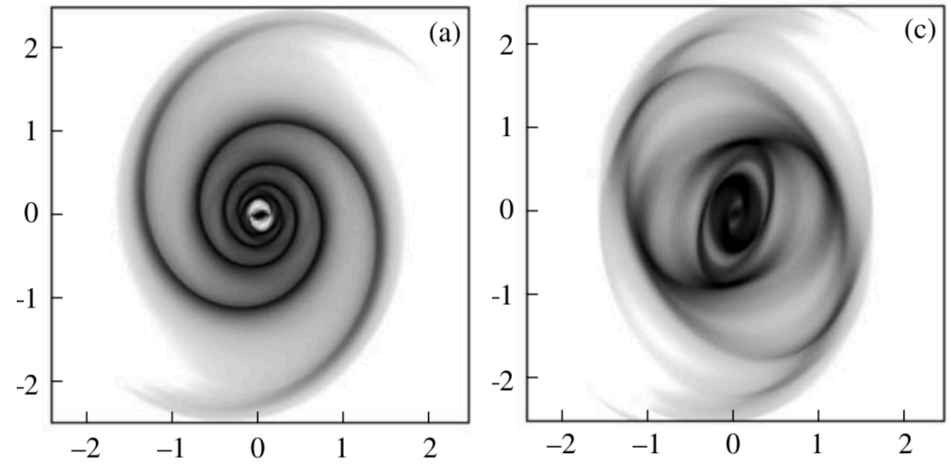
Halo was added on rapidly

Short run time : 2.7 Gyr



(Koperskov A.V. 2011)

Halo was added on in a short time.

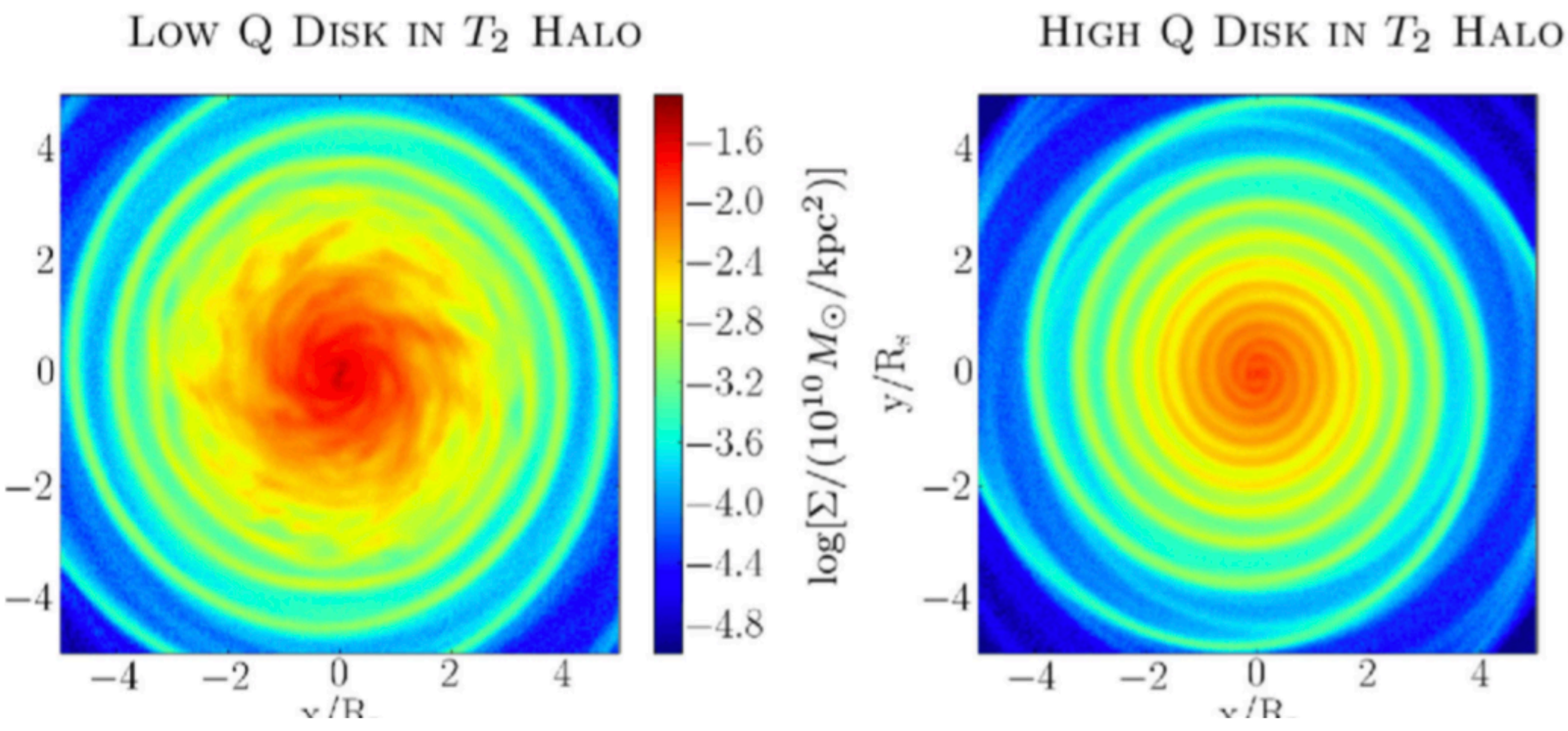


Previous studies

(Hu S. & Sijacki D. 2016)

Looked at the effect of triaxial halos on stellar discs with different activation periods.

Triaxial halo alone does not necessarily lead to spiral structures.



Thesis Aim

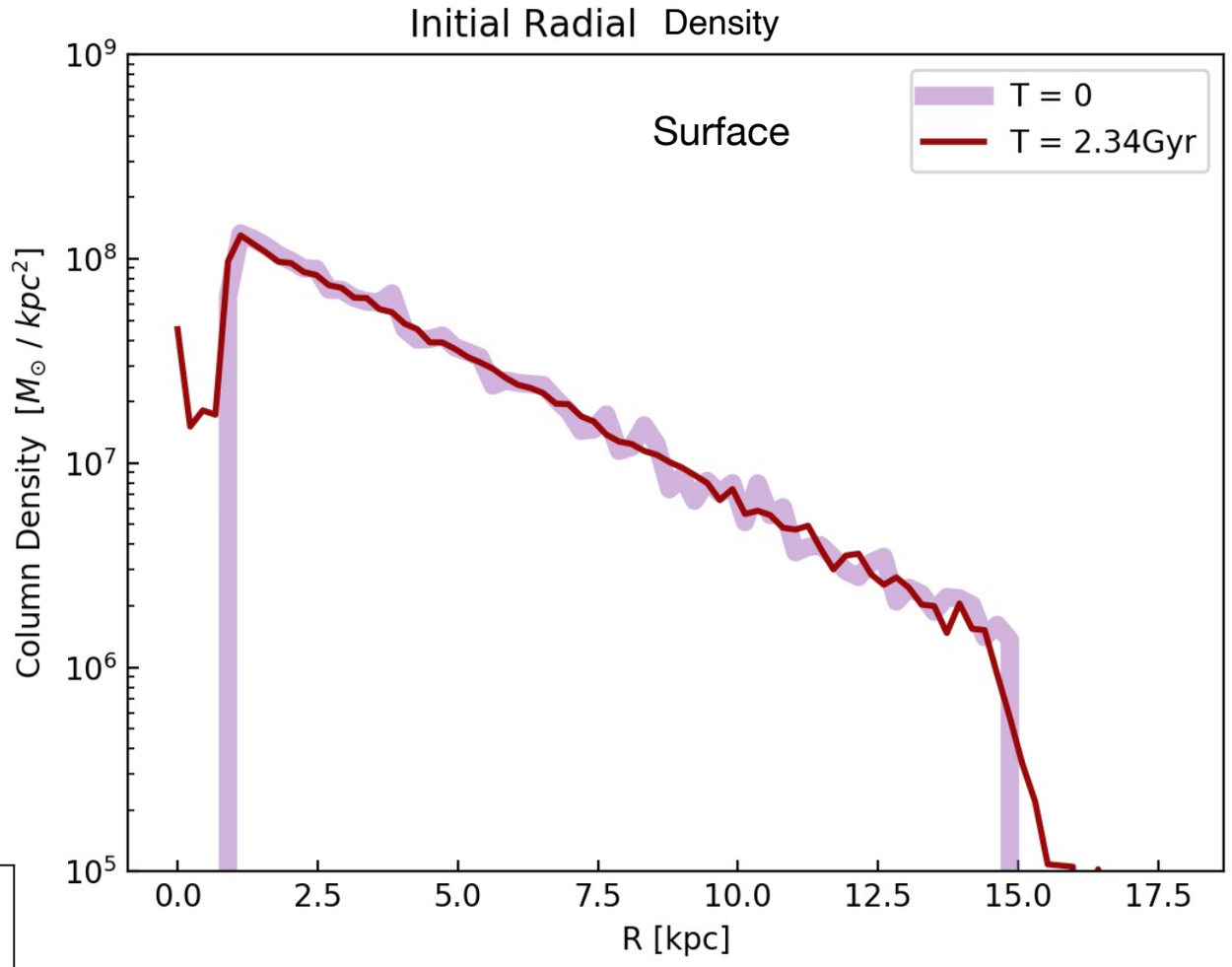
- **Investigate triaxial dark matter halo role on galactic gaseous disc still remains as a puzzle.**

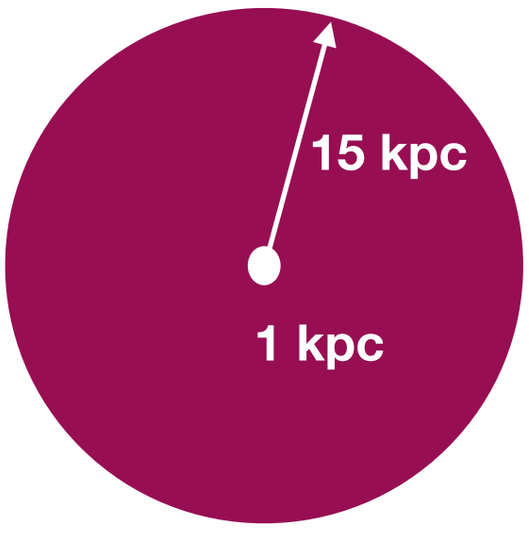
- **Compare gas response to different spiral-driven mechanisms.**
  1) **Triaxial halo**
  2) **Tidal interaction**
  3) **Density wave**
  4) **Dynamic arms**

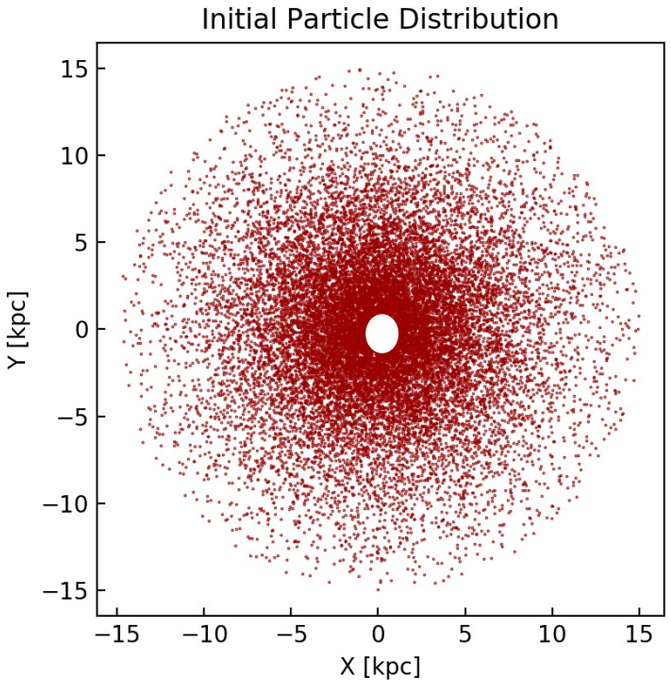
Initial Setup of Disc

Smoothed Particle Hydrodynamics
Price et al. (2018)

T	10^3 K
$\sigma(r)$	$Ae^{(-r/s)}$
s	3kpc
M_d	10^{10}Mo
N	10^7







The initial rotation velocity is set to be like MW rotation curve.

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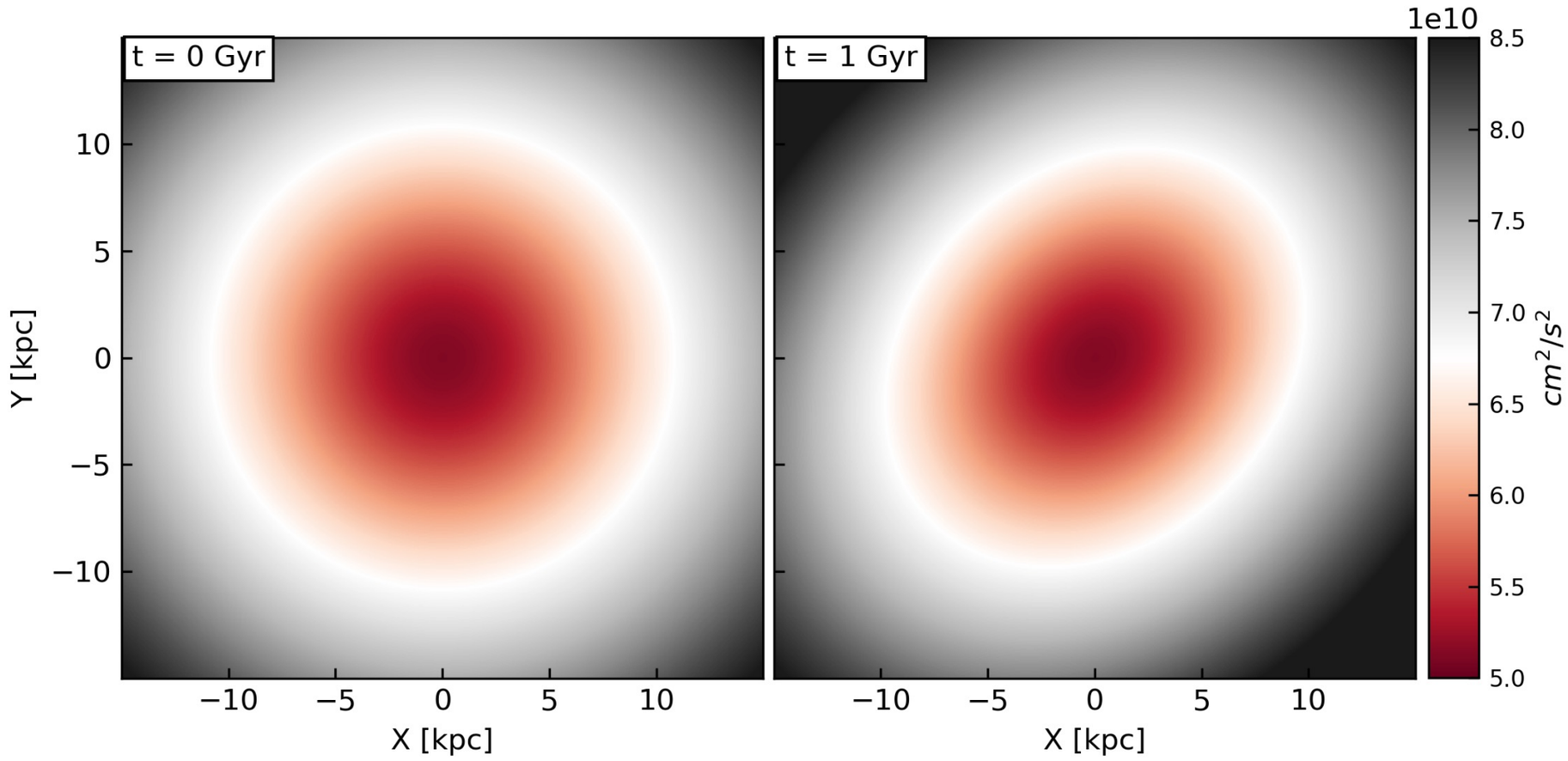
Perturbations 1

Triaxial Dark Matter Halo

Khoperskov et al. (2003, 2011)

Halo Contour Plot



The plot is from rotating halo, but in our simulation, halo is set to be static.

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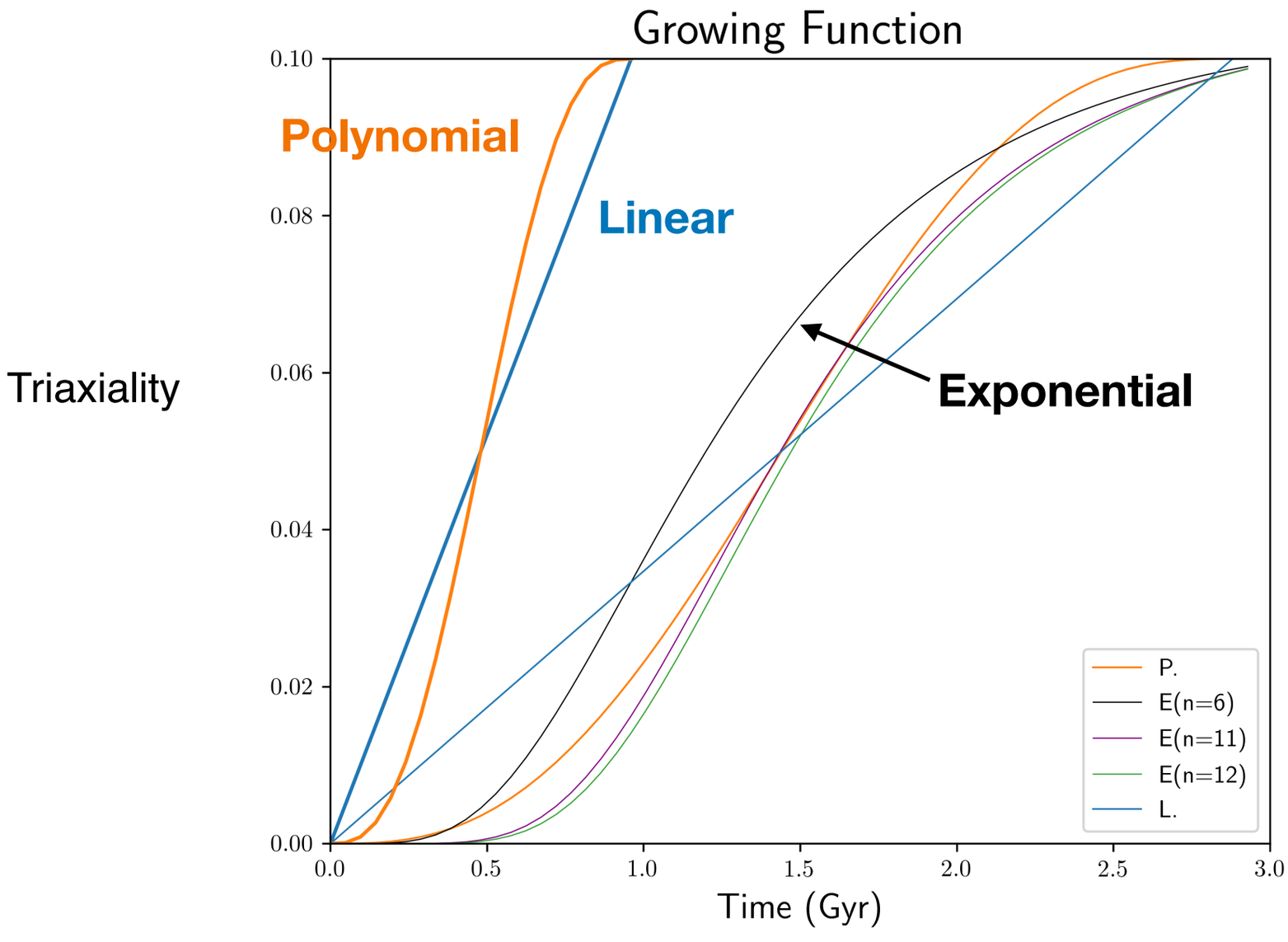
Perturbations

Triaxial Dark Matter Halo

Khoperskov et al. (2003, 2011)



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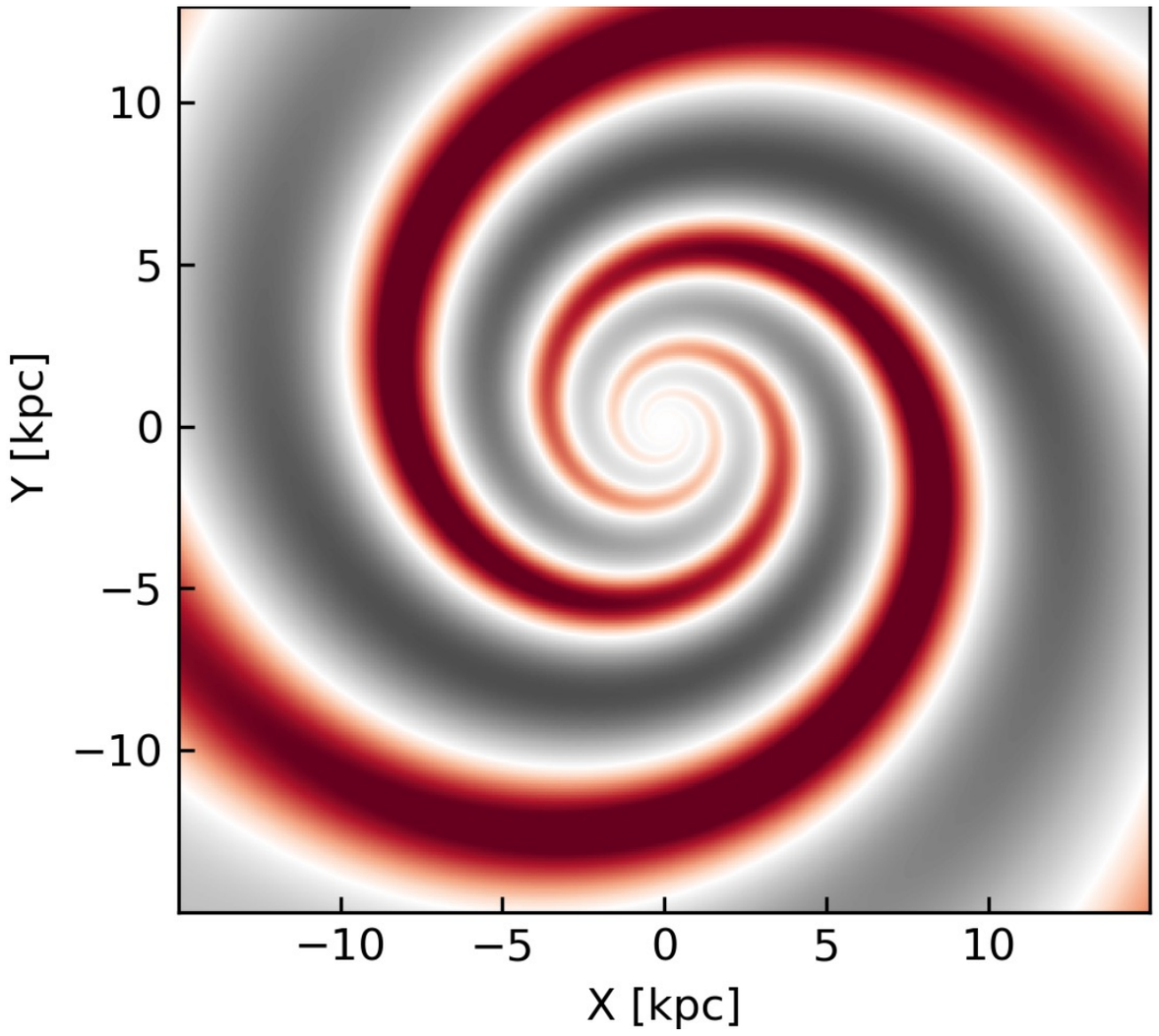
Perturbations 2

Density Wave Potential

Cox & Gomez et al. (2002)



Rotates like a rigid body with a constant speed.

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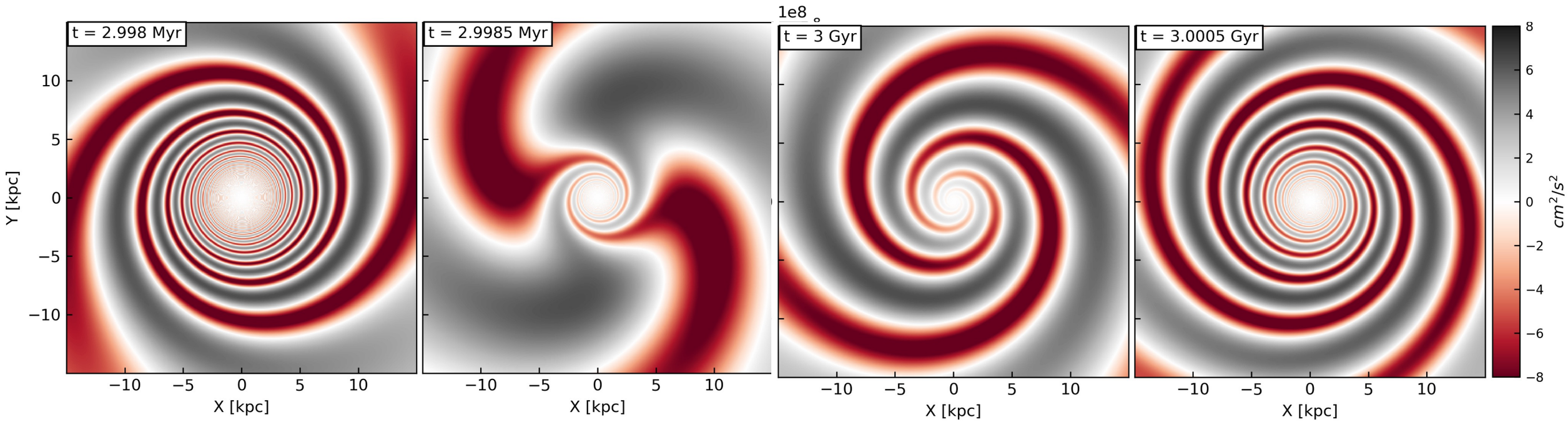
Perturbations 3

Dynamic Arm Potential

Hunt et al. (2018)

Spirals + Co-rotation = winding effect



* galaxy rotates anti-clockwisely in these plots.

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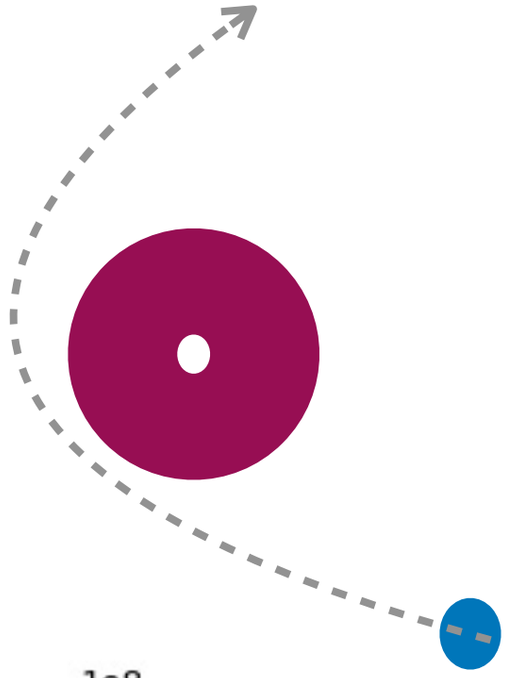
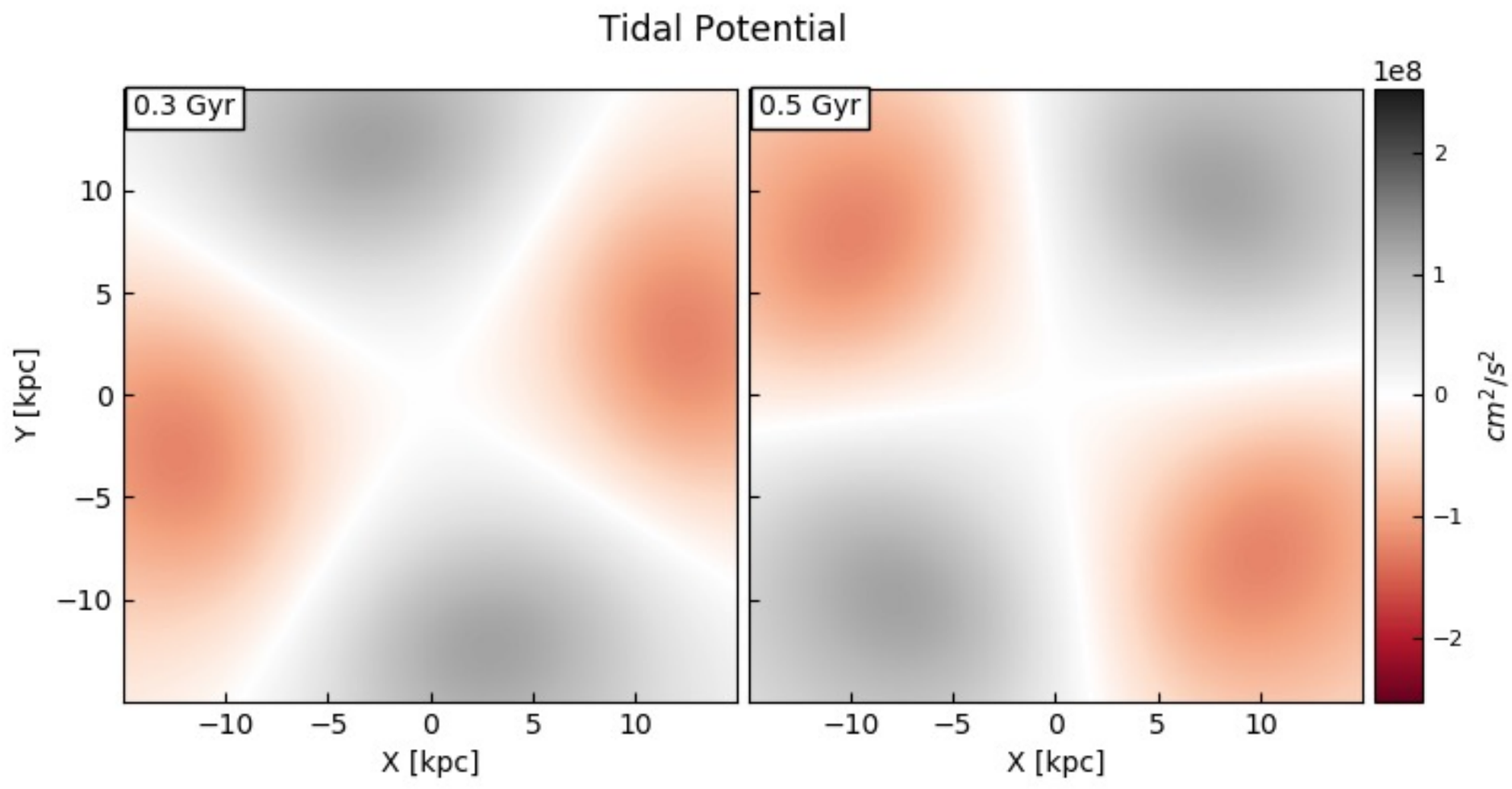
Perturbations



Tidal Interaction

Sellwood et al. (2019)



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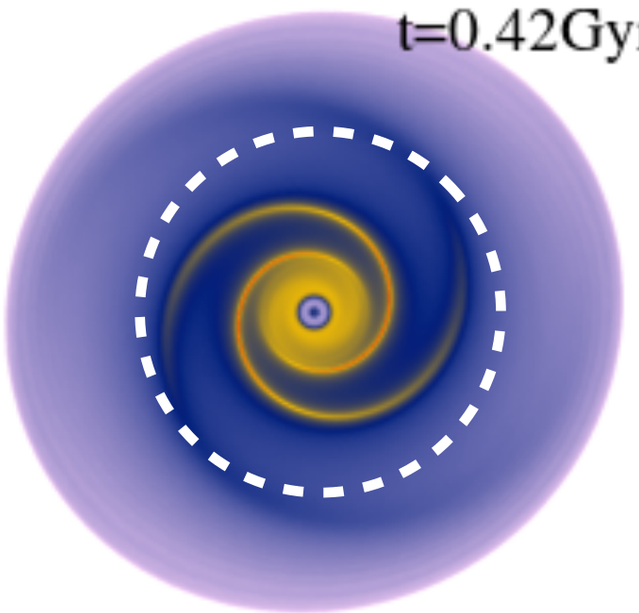
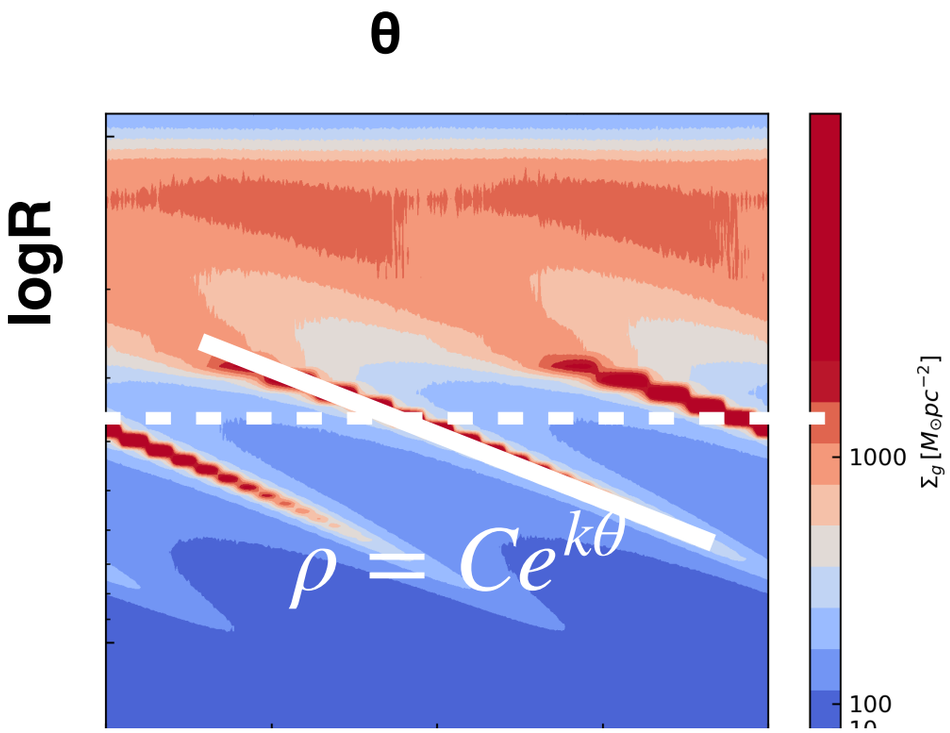
Analysis Technique

logR - θ Density Heatmap





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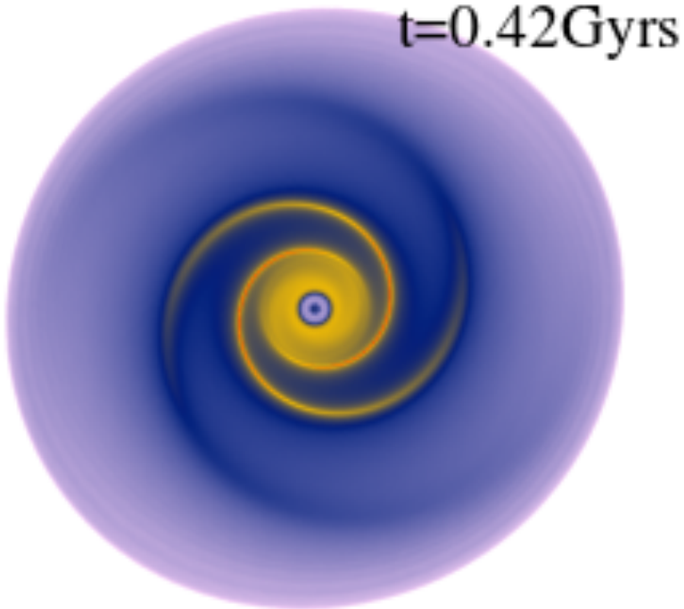
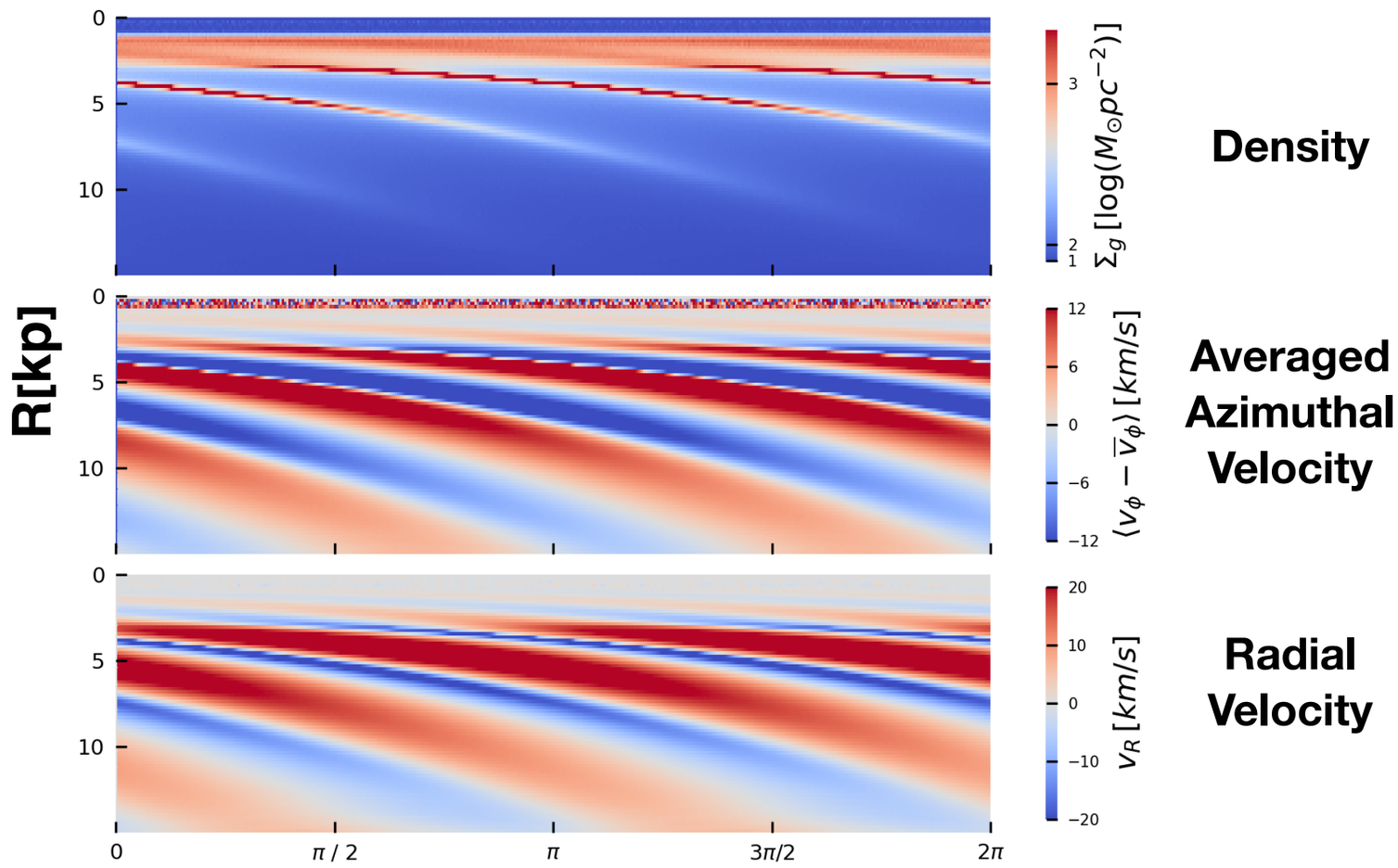
Analysis Technique

Velocity Heatmap





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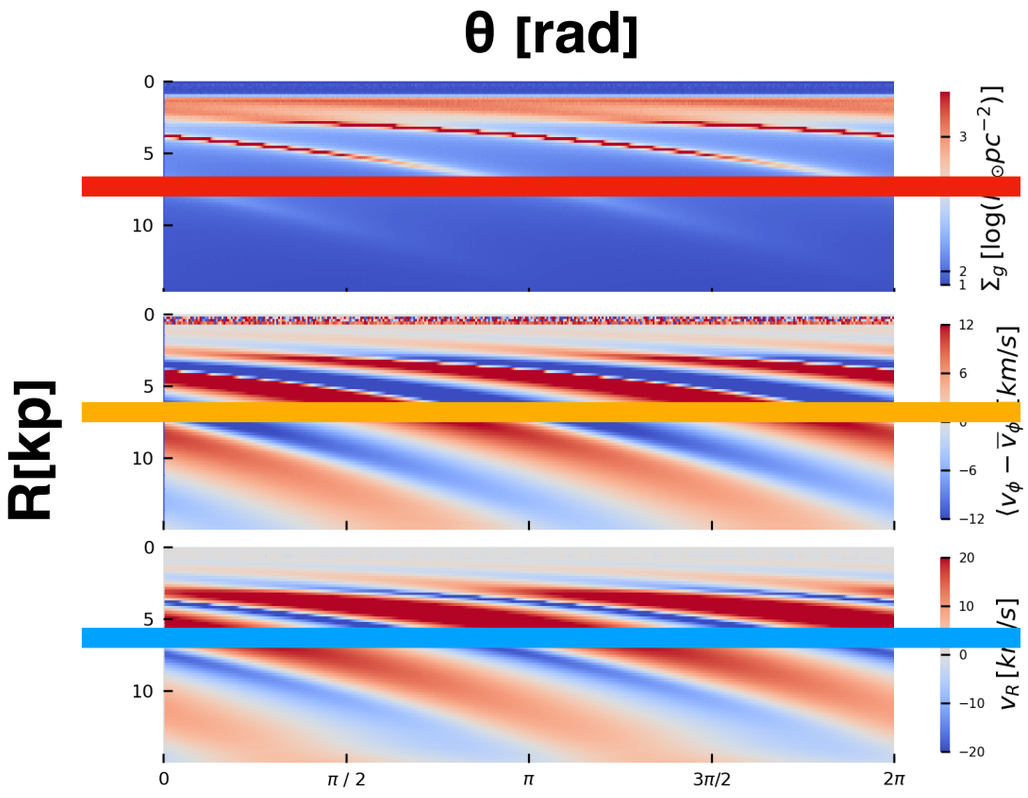
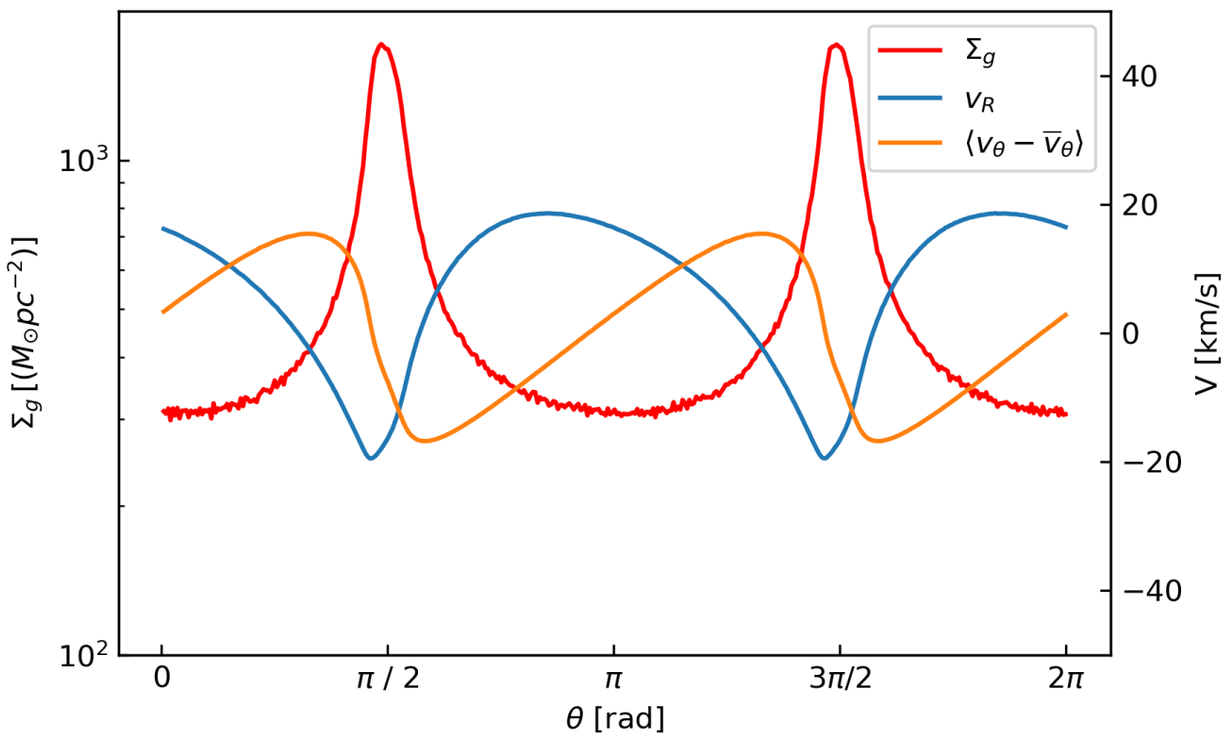
Analysis Technique





We explore how the profiles of the density and velocities relate to each other.

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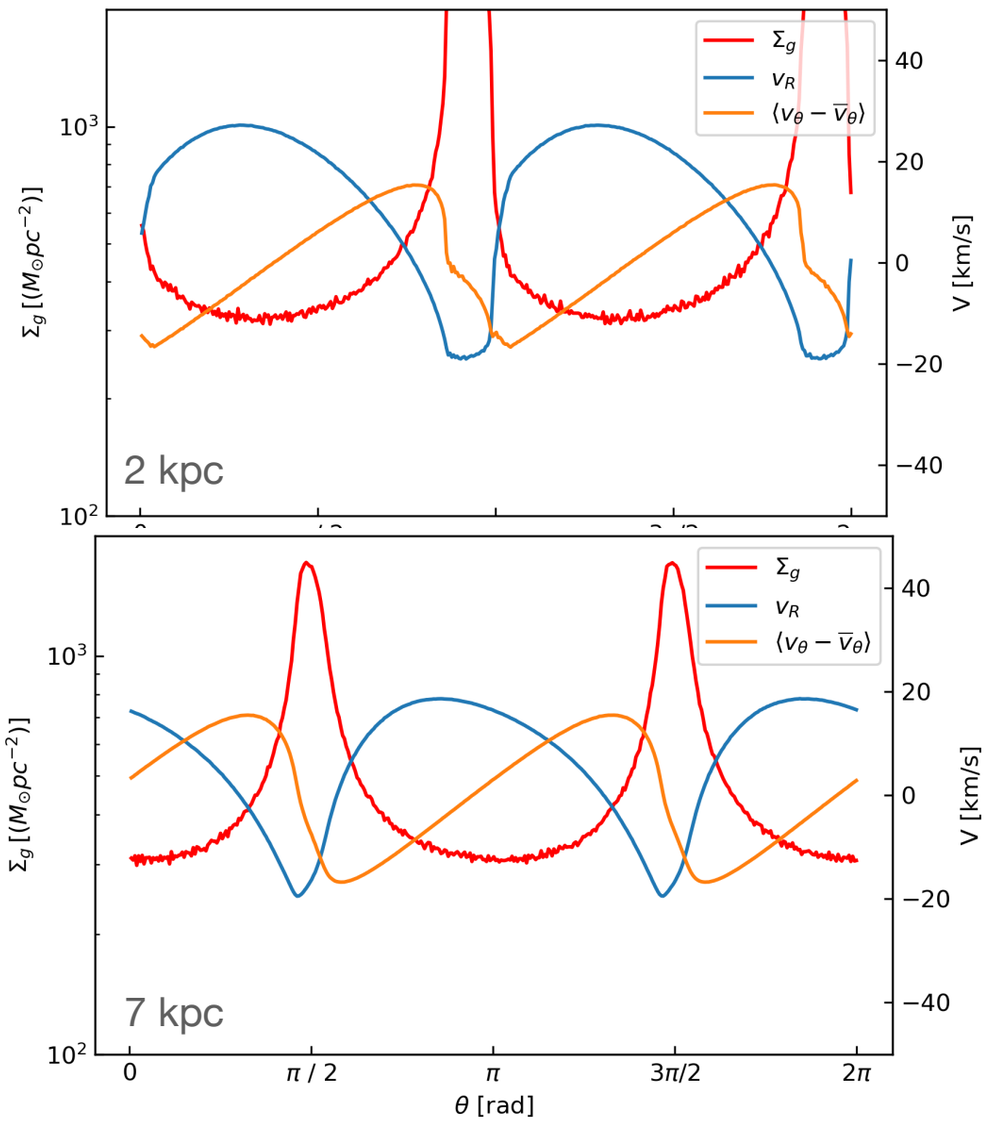
Analysis Technique

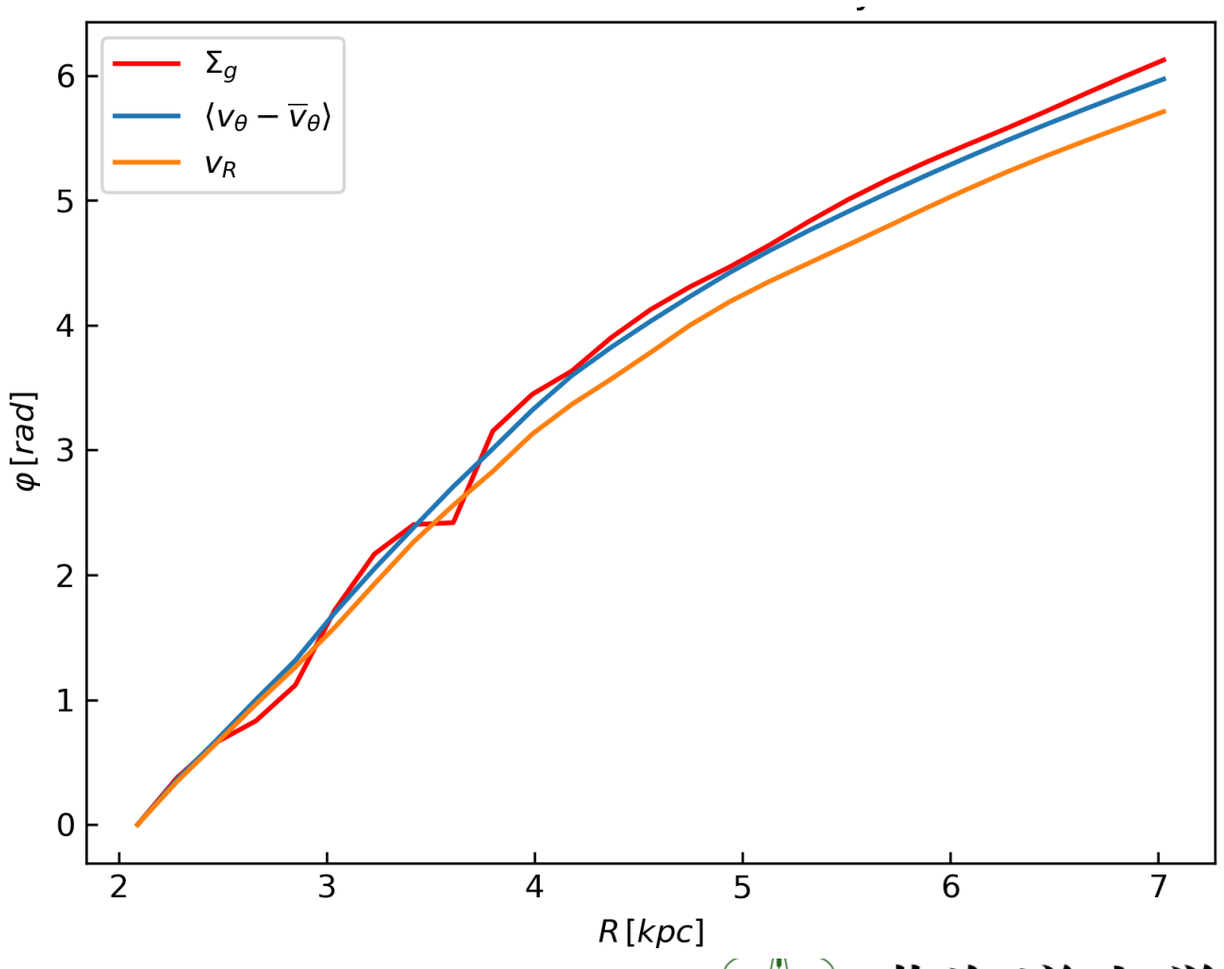
Fourier Decomposition

Pettitt A.R et al.(2015)

$$I(r) = 1 + \sum_{m=1}^{\infty} A_m(r)\cos m[\phi - \phi_m(r)]$$

$$\phi_2(r) - \phi_2(r_0)$$





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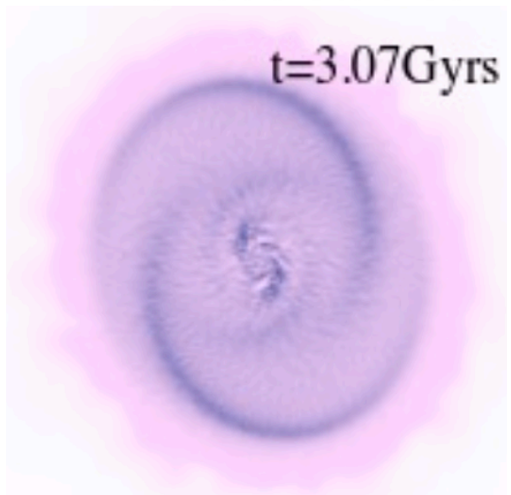
Low Resolution Tests of Halo

Previous studies

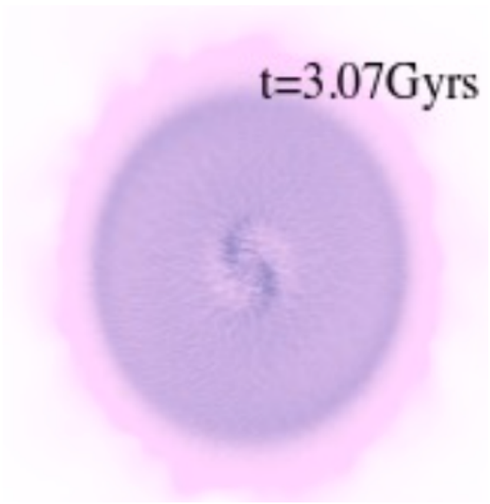
$T = 10^3 K$

$M_d = 10^8$ Mo

$N = 10^4$



Adiabatic growth for triaxial halo

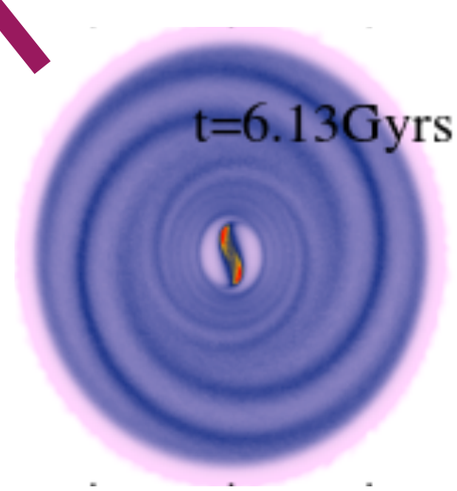


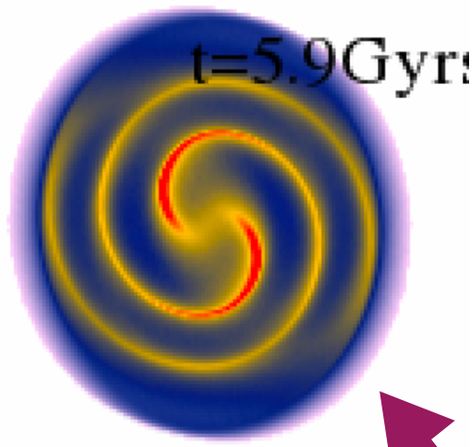
Higher resolution

$T = 10^4 K$

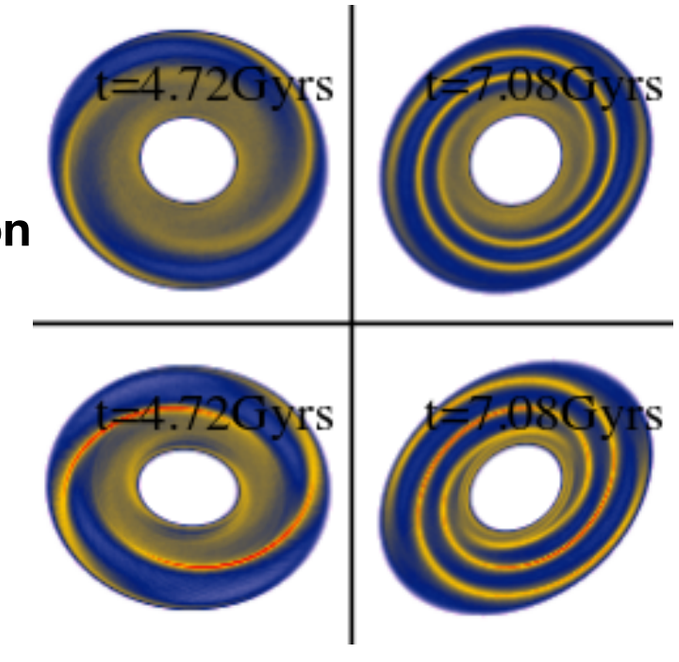
$M_d = 10^8$ Mo

$N = 10^6$





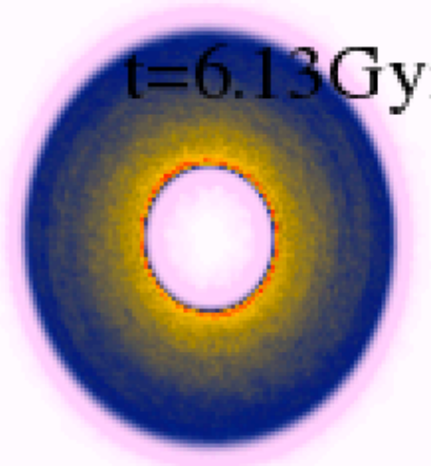
Triaxiality matters



halo

halo

Growth function matters



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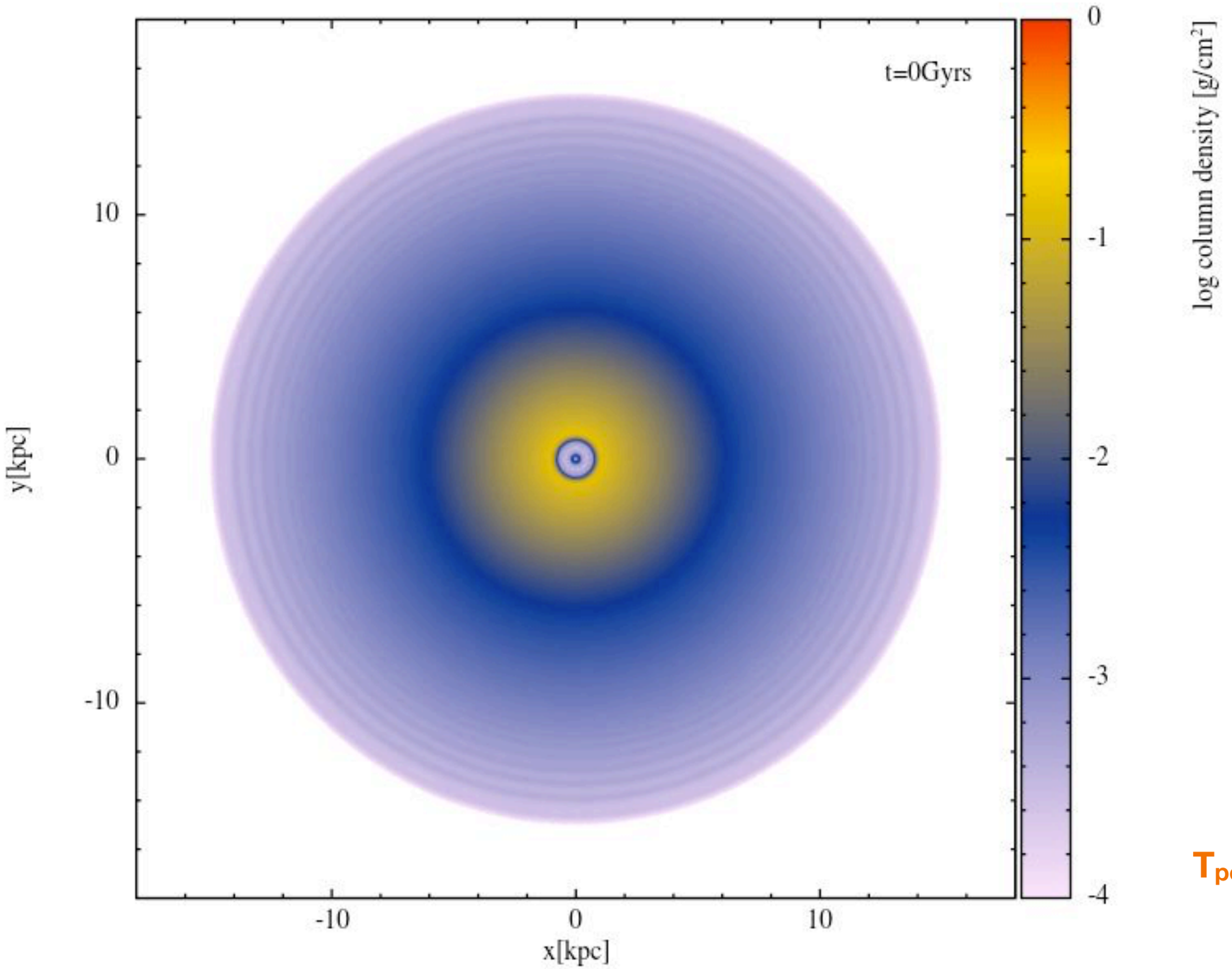
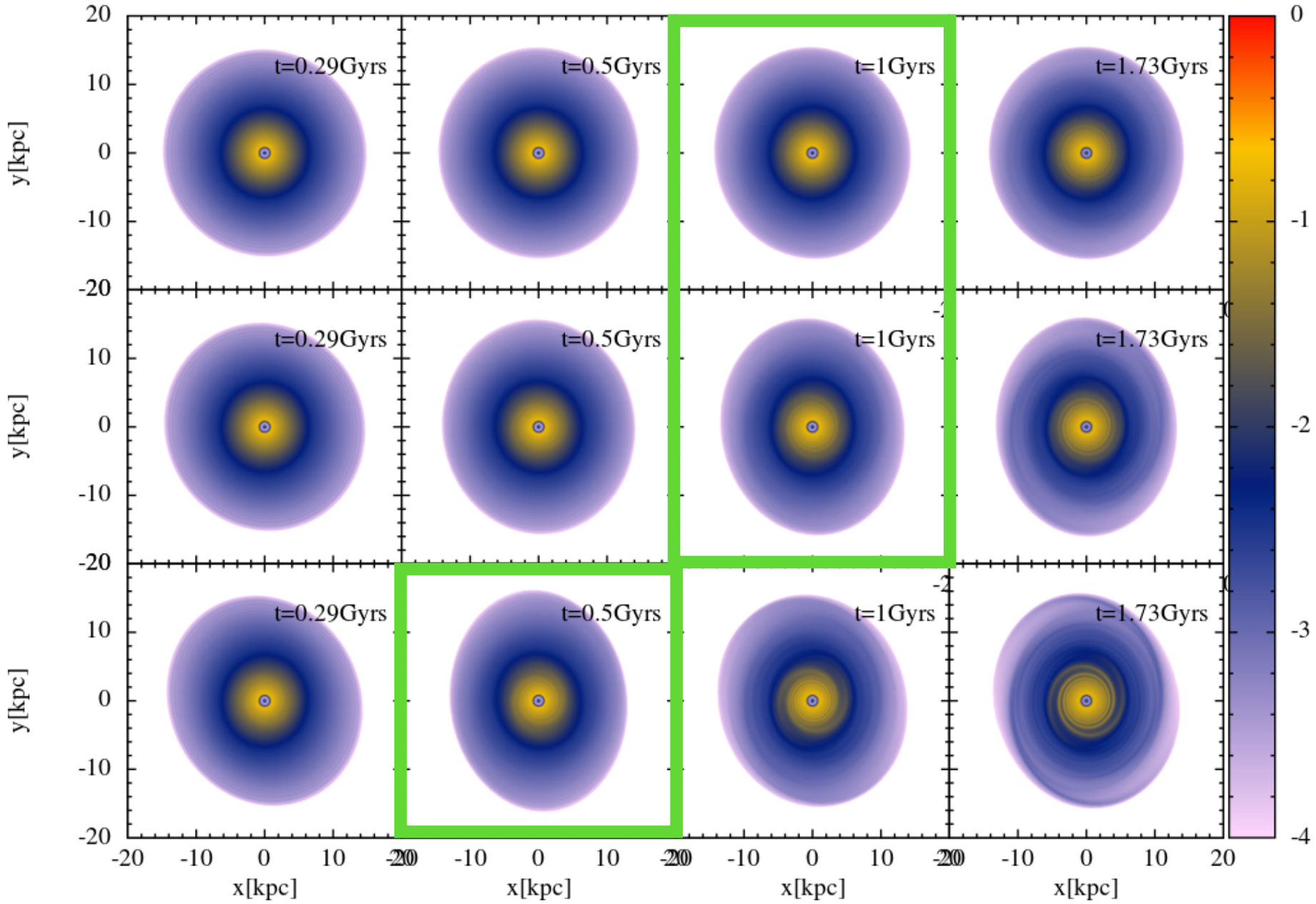
Halo



Linear
q = 0.1
T_{peak} = 1Gyr

Triaxial Dark Matter Halo

Exponential disc with bulge + High Resolution N = 10^7



Linear
q = 0.1
T_{peak} = 1Gyr

Polynomial
q = 0.2
T_{peak} = 1Gyr

Polynomial
q = 0.2
T_{peak} = 0.5Gyr

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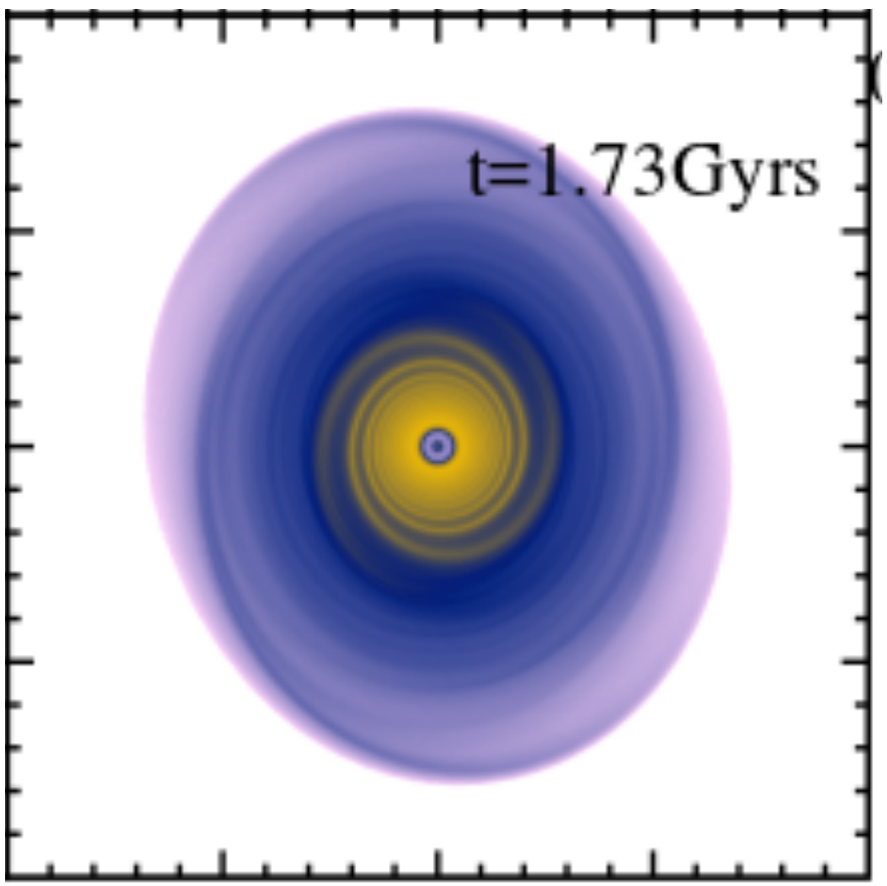
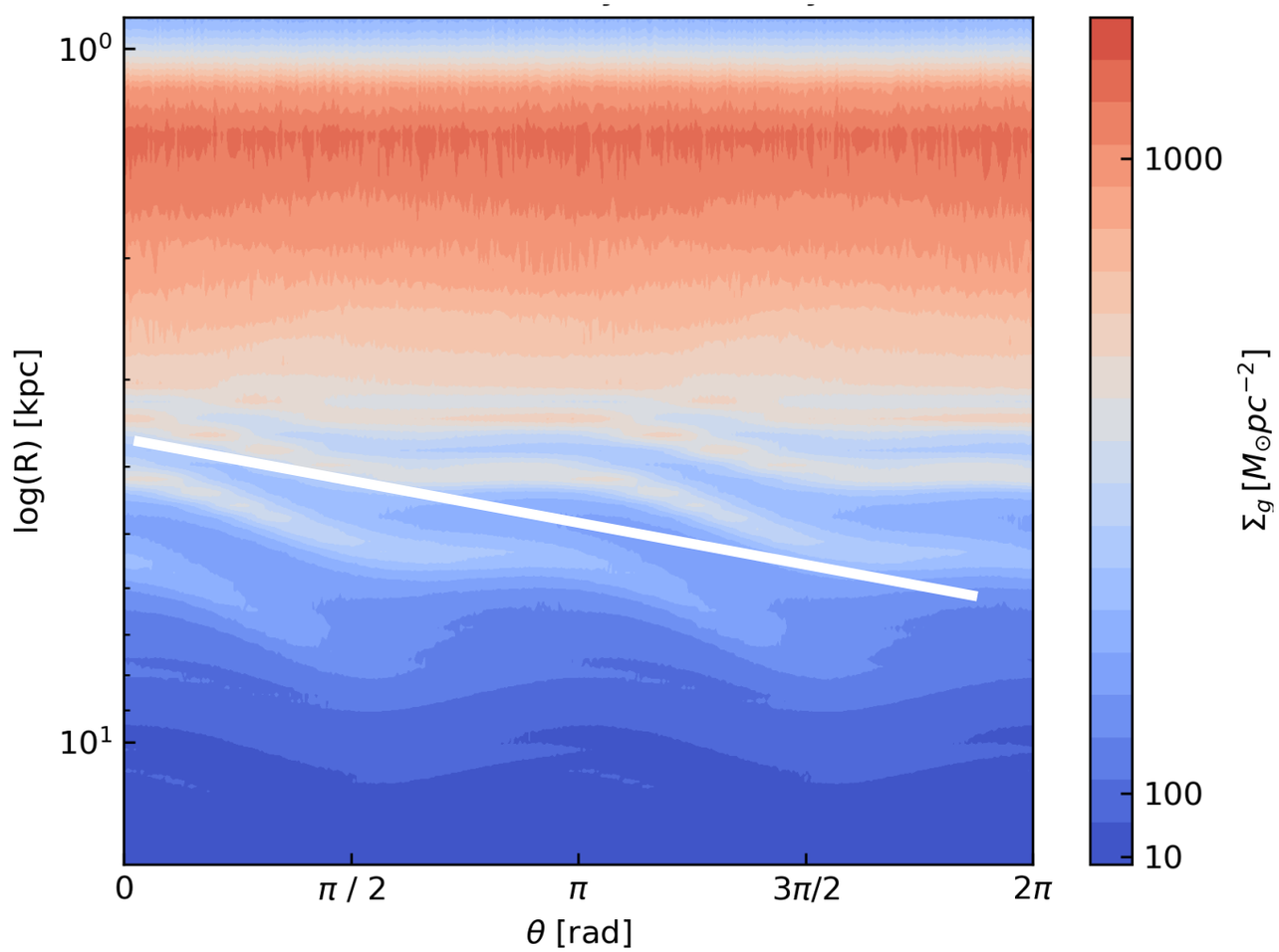
Triaxial Dark Matter Halo





Induced arms are not logarithmic.

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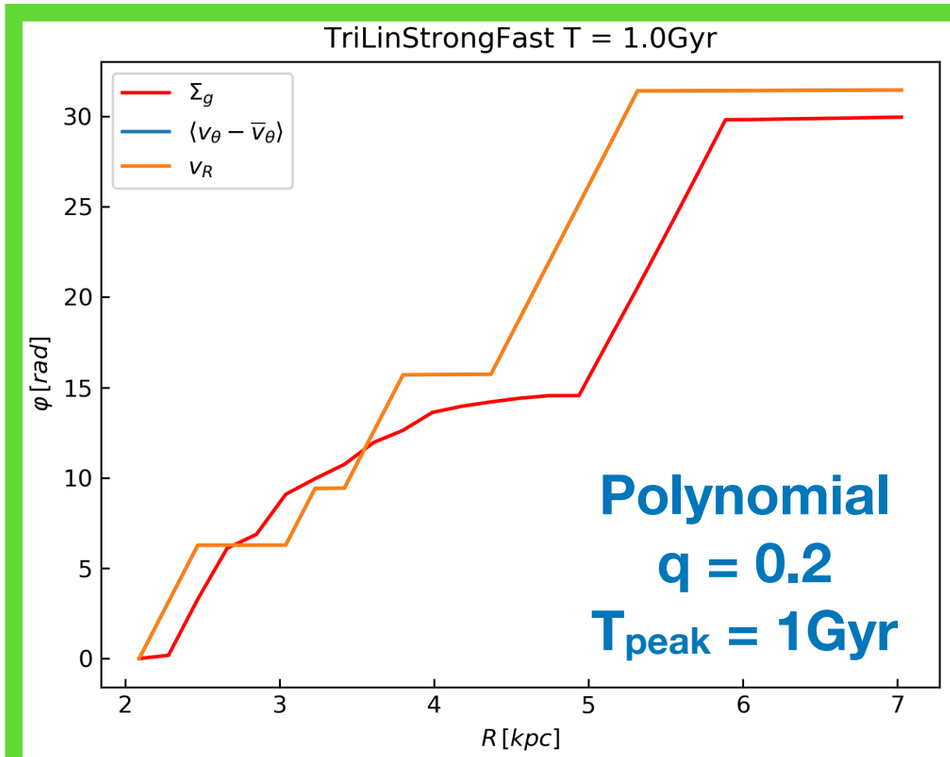
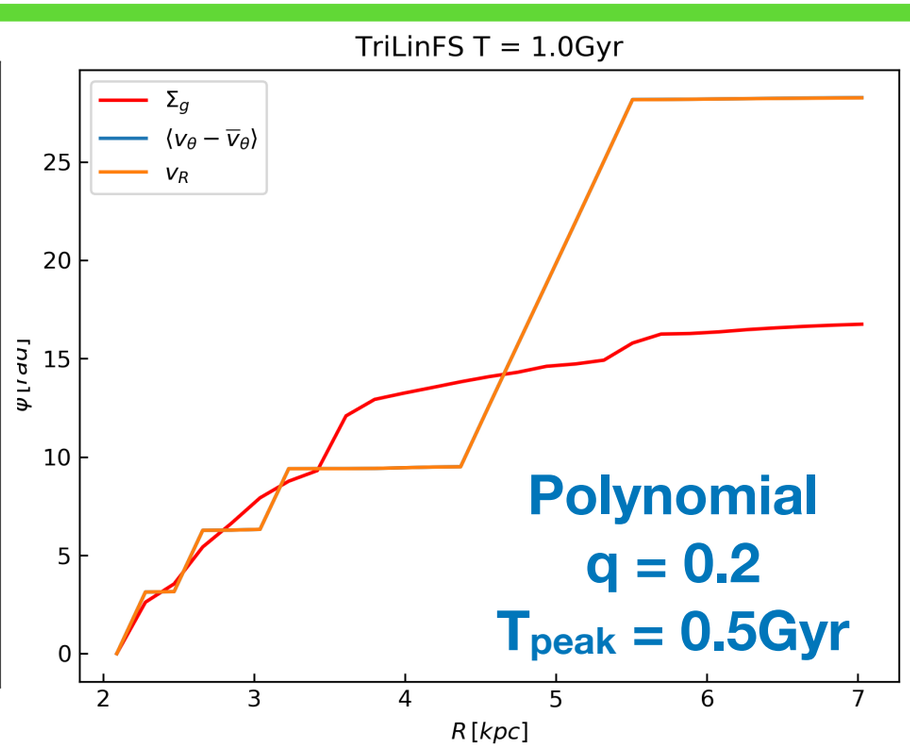
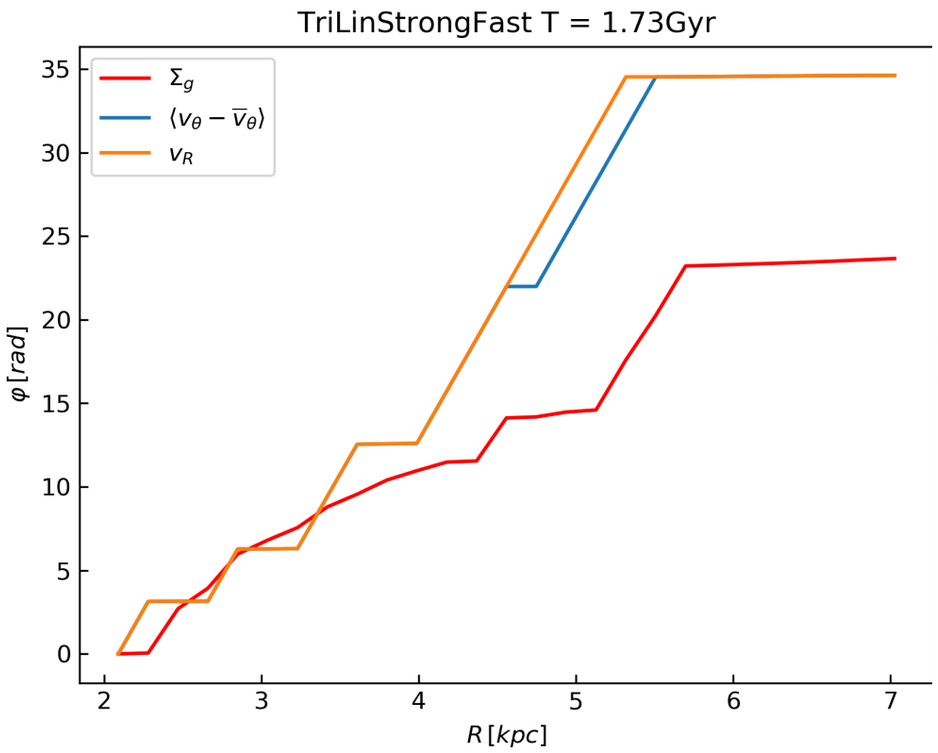
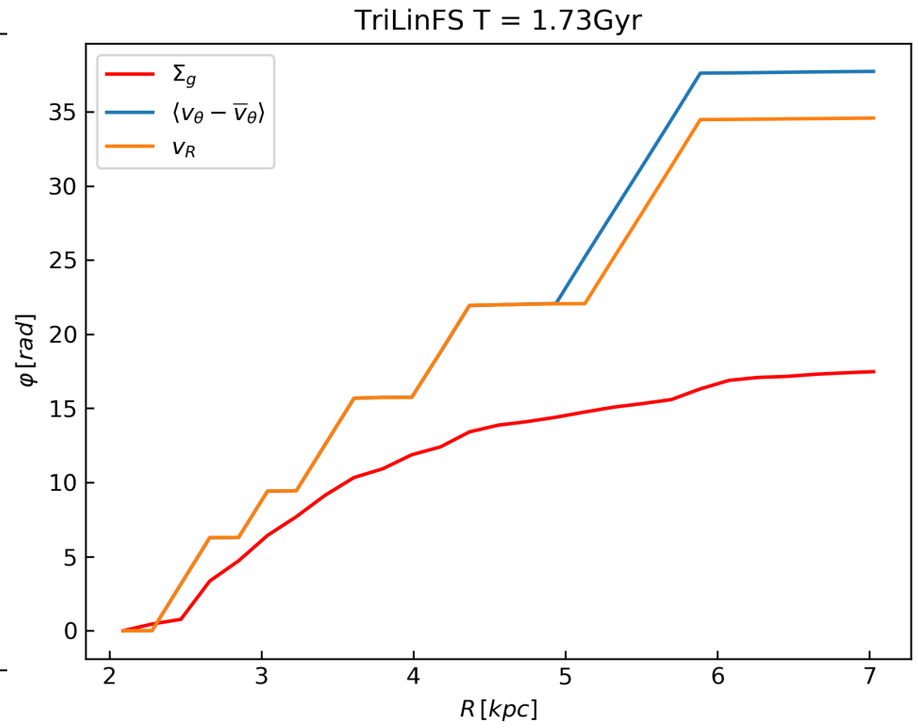
Triaxial Dark Matter Halo





Different T_{peak}





One orbital period after T_{peak}

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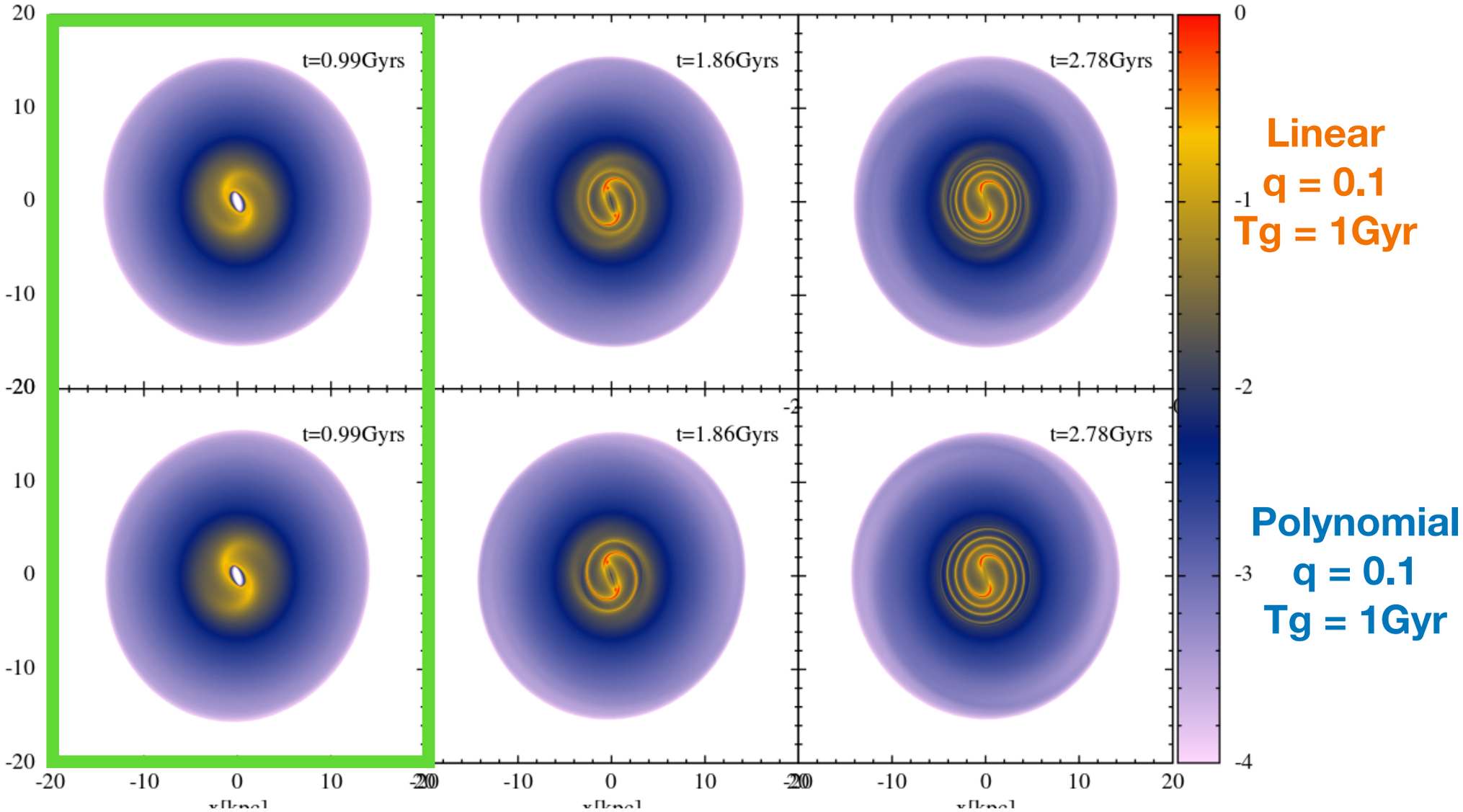
Triaxial Dark Matter Halo

Exponential disc without bulge + High Resolution N = 10^7



T_p $1T_r$ $2T_r$

Induced arms are highly sensitive to rotation curve.

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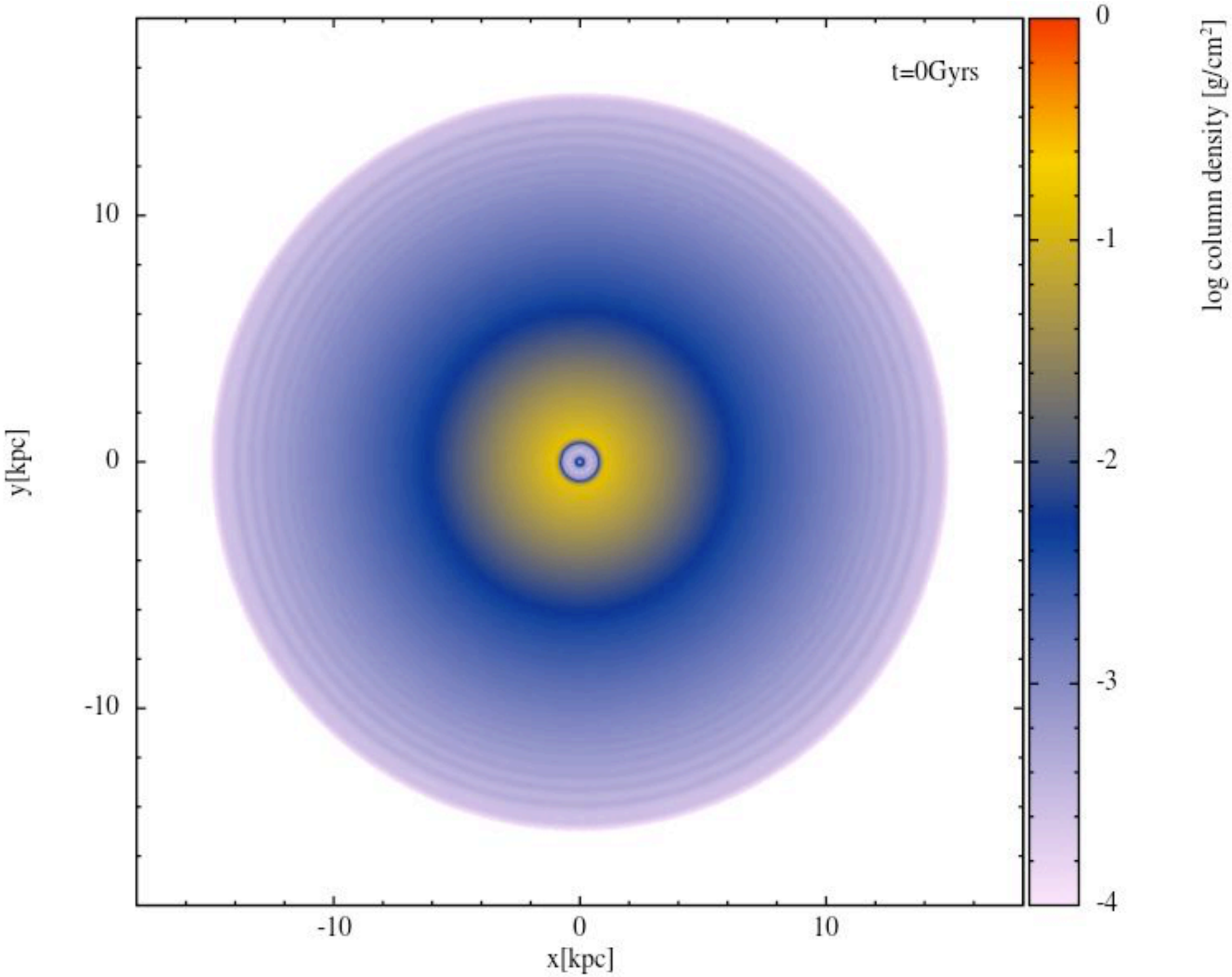
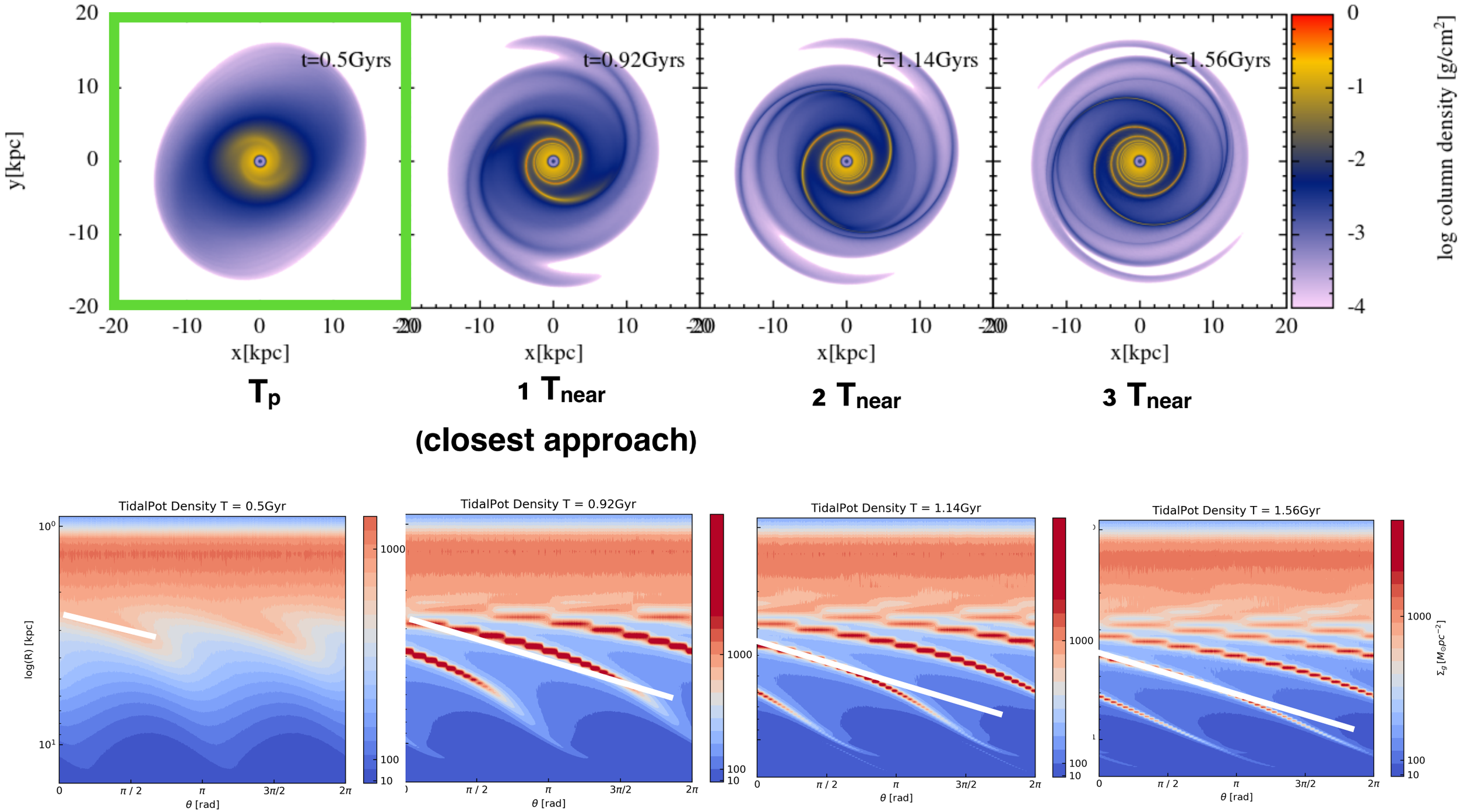
Tidal Interaction

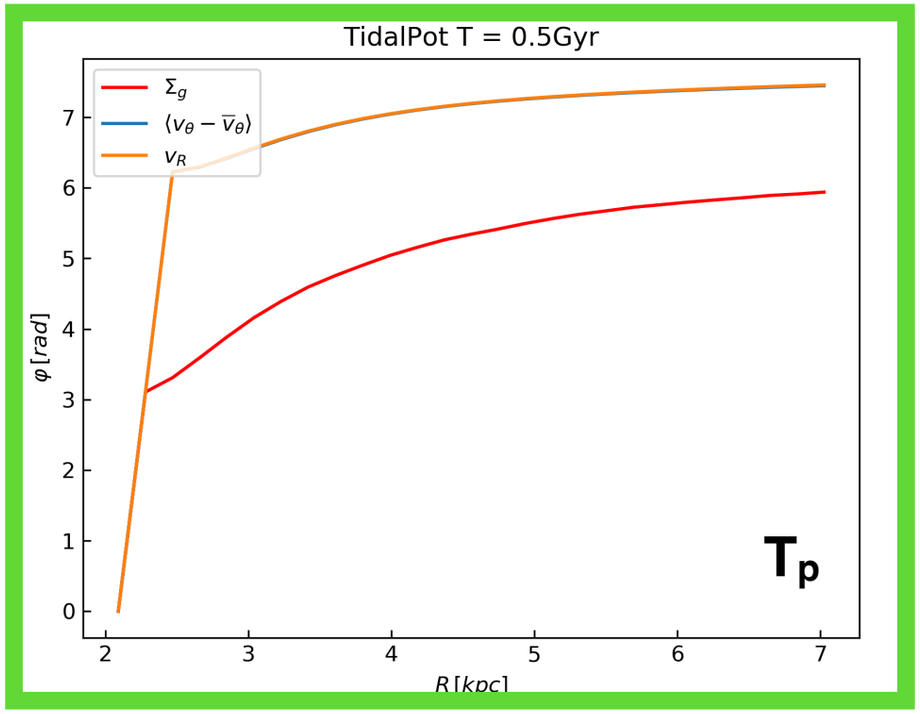


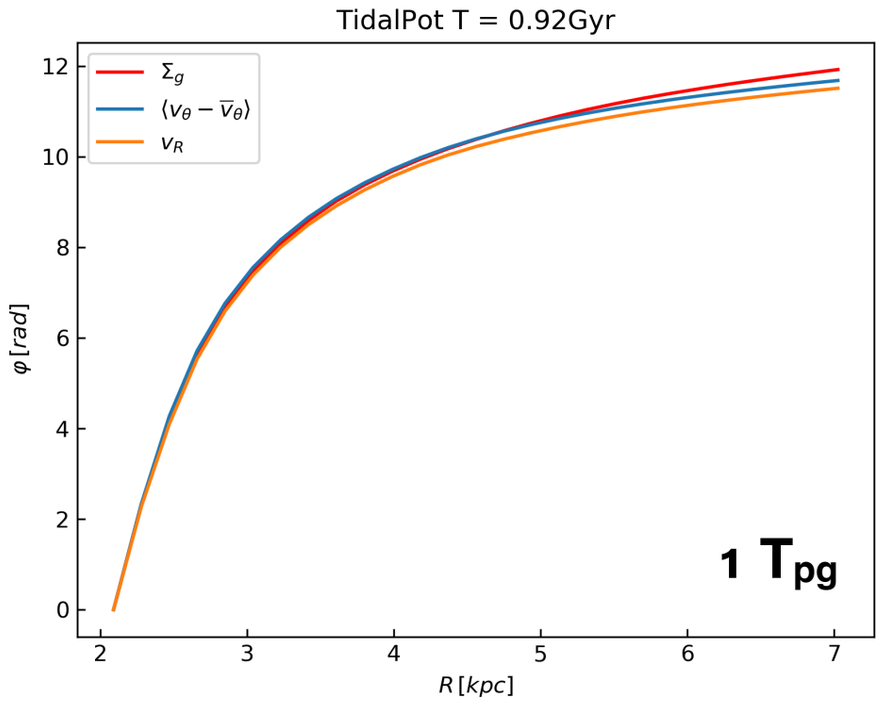
Tidal Interaction

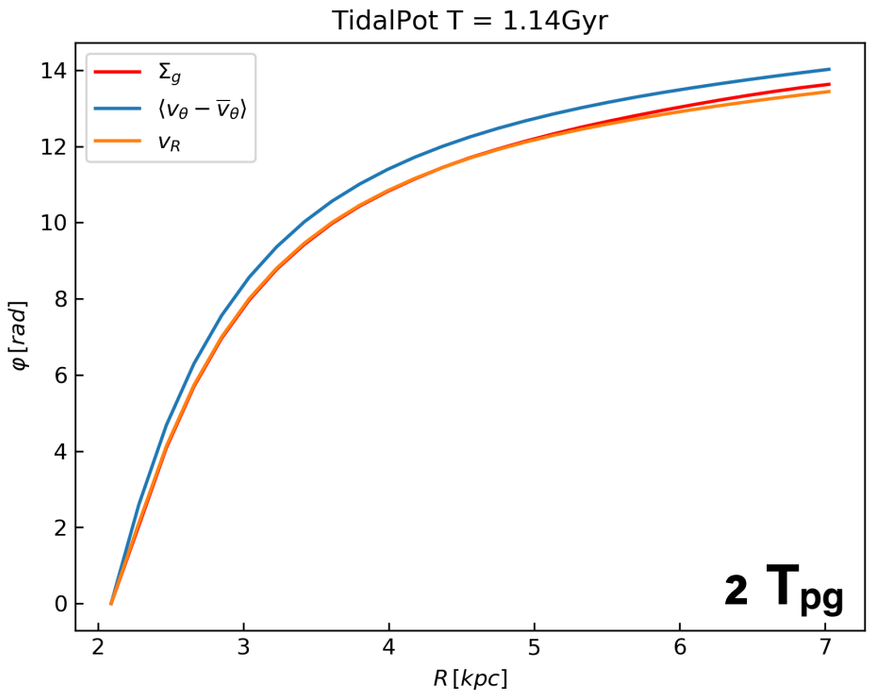


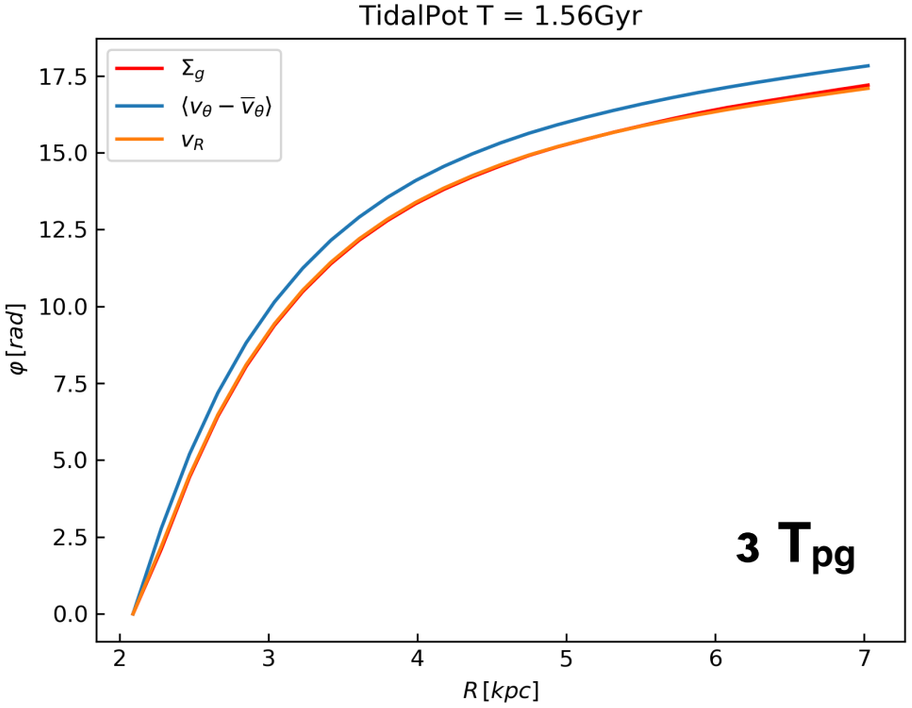
T_p **1 T_{near} (closest approach)** **2 T_{near}** **3 T_{near}**

Tidal Interaction









The offset between velocity and densities strongly time-dependent.

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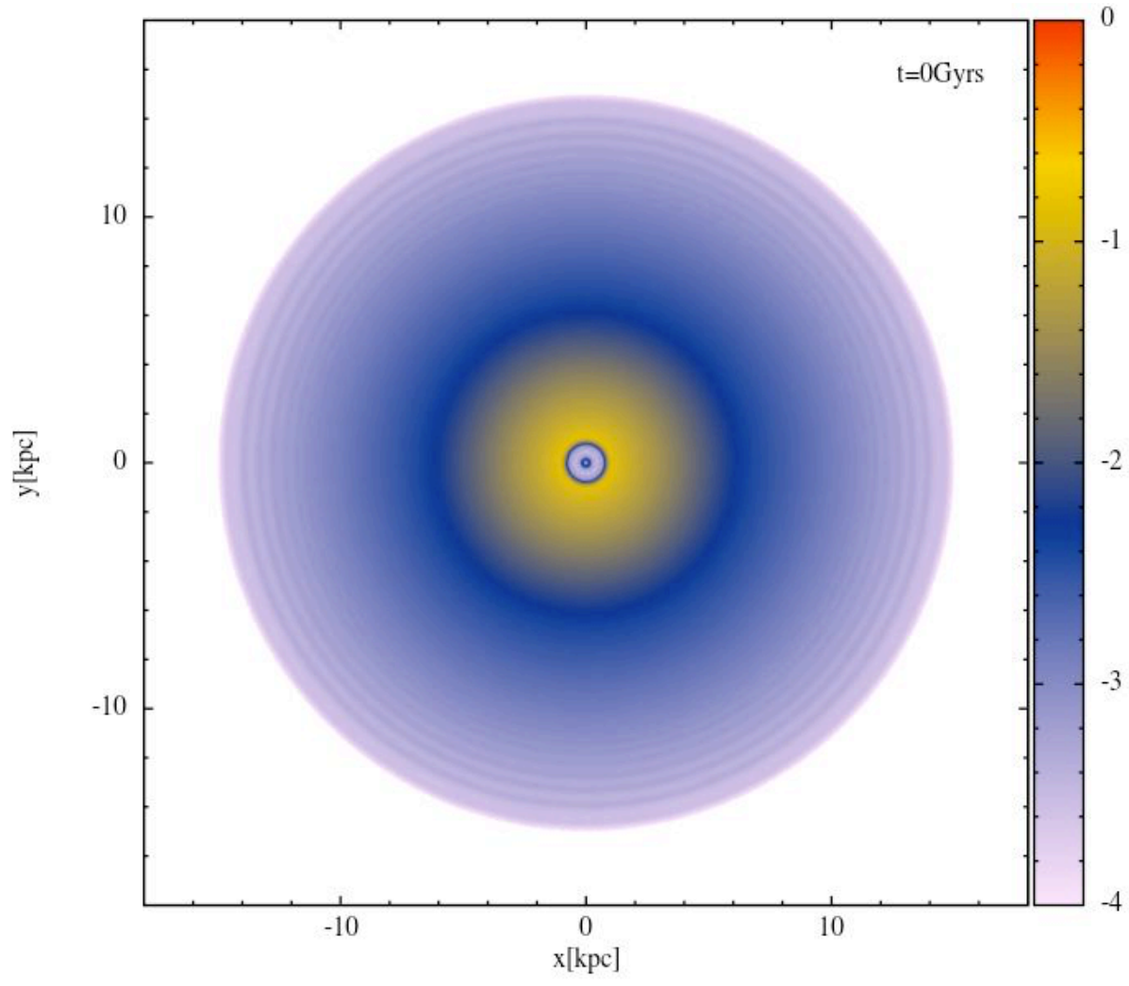
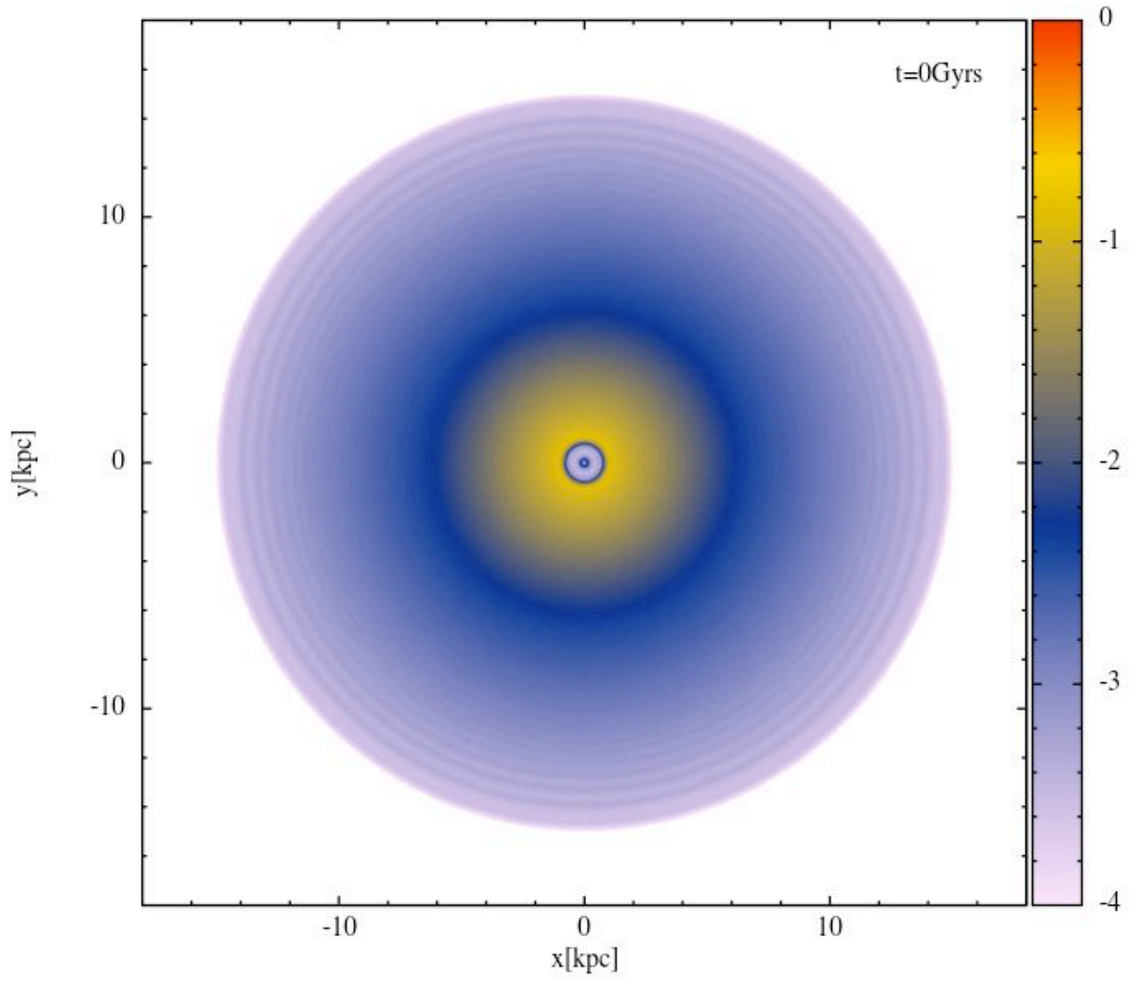
Density Wave & Dynamic Arms

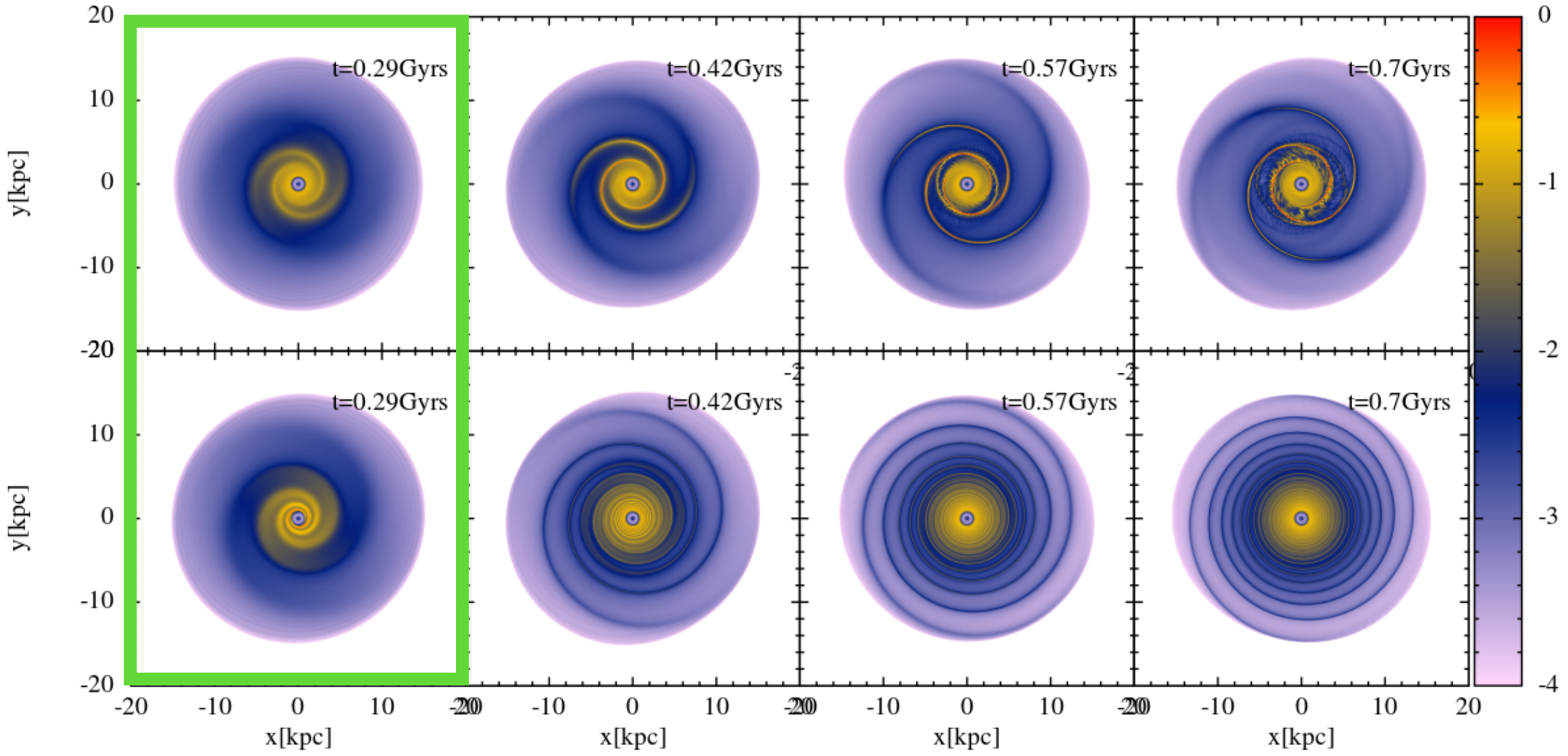


DW
[rigid rotation]



DA
[winding rotation]

Density Wave & Dynamic Arms



DW

DA

T_p 1/3 T_r 2/3 T_r 1T_r

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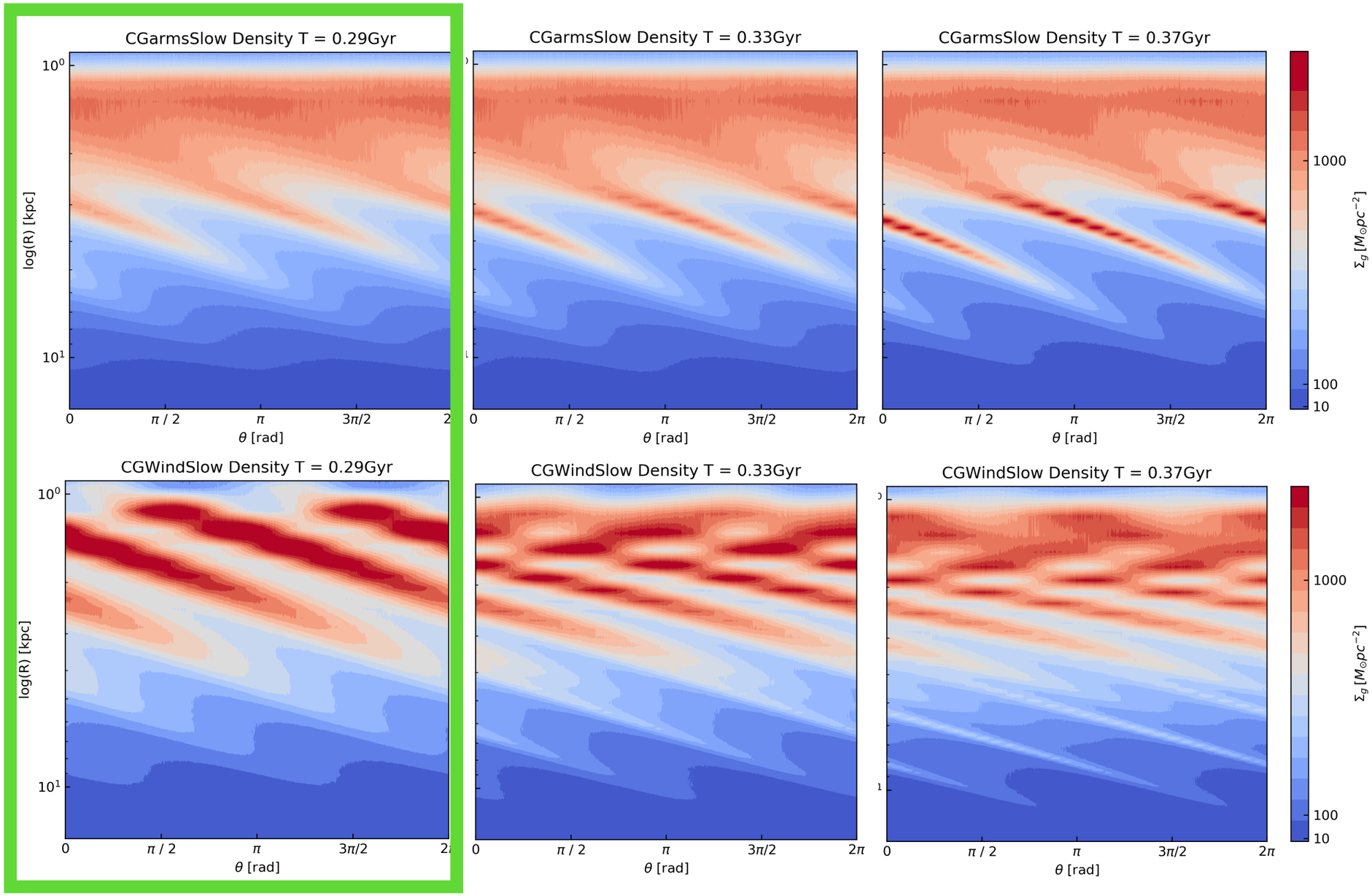
Density Wave & Dynamic Arms



DW

DA

T_p $1/3\ T_r$ $2/3\ T_r$

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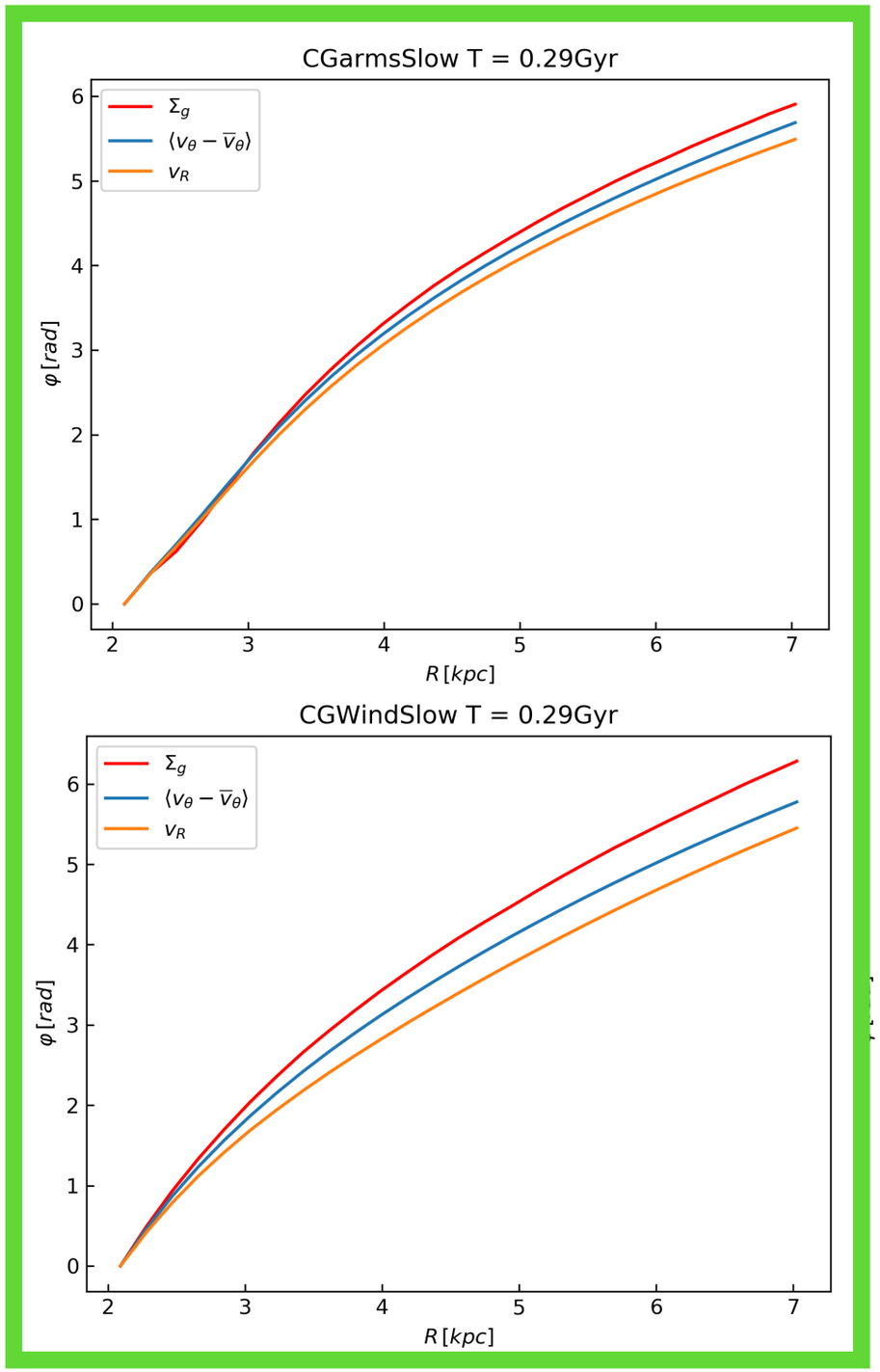
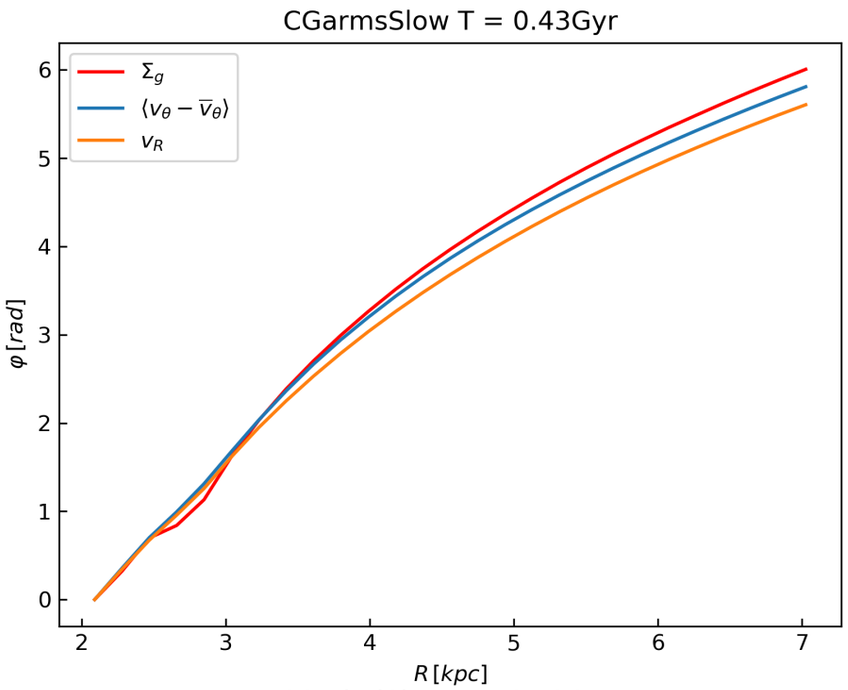
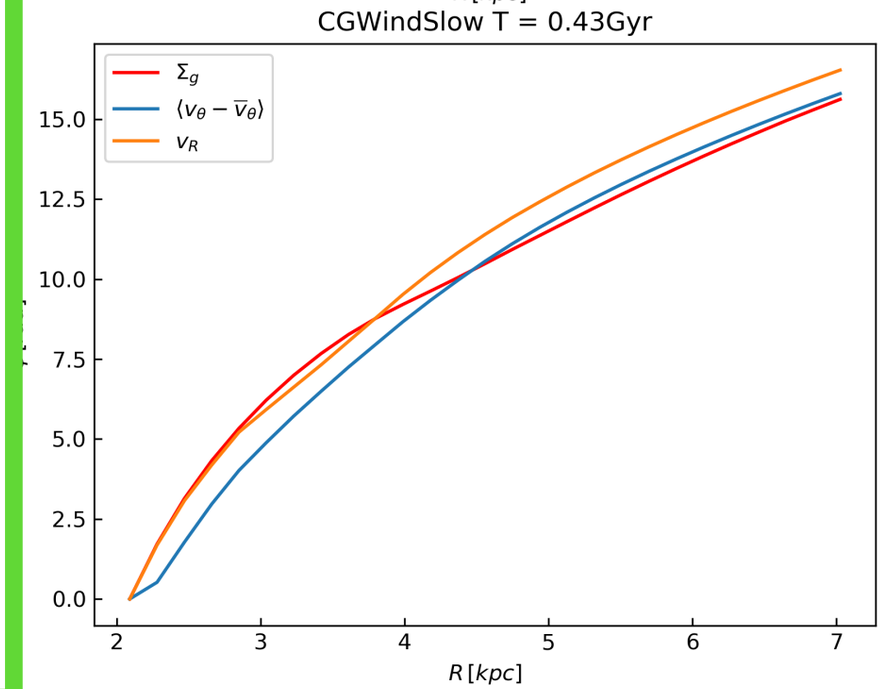
Density Wave & Dynamic Arms



T_p





$1T_r$

DW

DA

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- **Triaxial dark matter halo does not necessarily induce spirals in gaseous galactic disc if its growth is adiabatic enough.**

- **Spirals generated by triaxial dark matter halos are very sensitive to the specific galaxy disc parameter, such as surface density and distribution, rotation curve etc.**
  (Whereas results in previous studies seem to suggest they are easy to generate.)

- **Both of the two-armed spirals induced by triaxial dark matter halo and tidal component are not logarithmic. Together with the difference in relative phases of the velocities and density peaks, this could be a diagnostic of the nature of spiral arms in real observed galaxies.(Though halo that could generate notable spirals is not suggested by latest GAIA data for MW galaxy.)**

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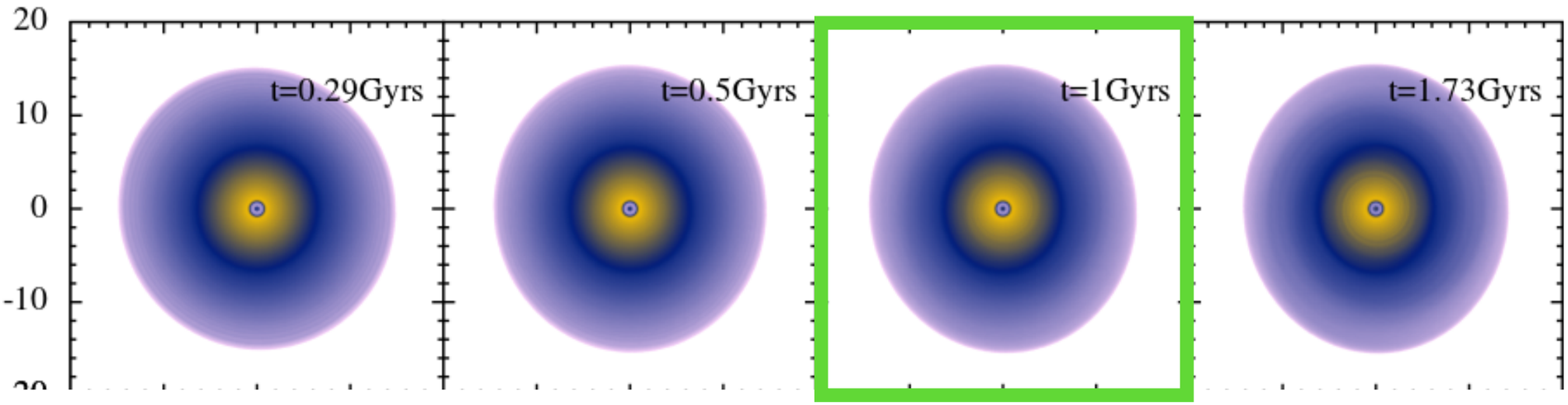
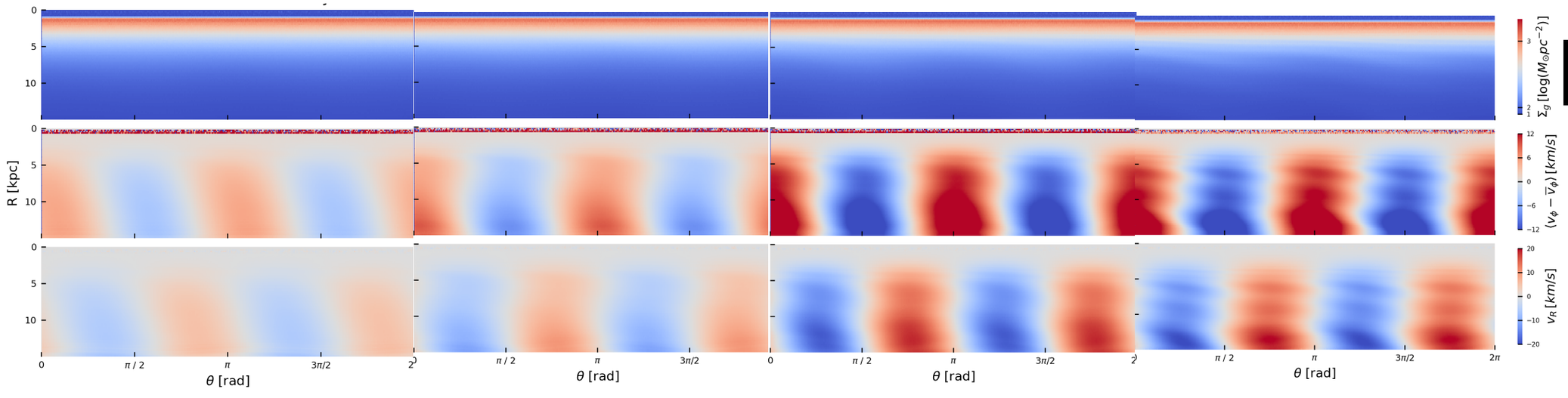
Triaxial Dark Matter Halo

Exponential disc with bulge + High Resolution N = 10^7



Linear
q = 0.1
Tg = 1Gyr



Label

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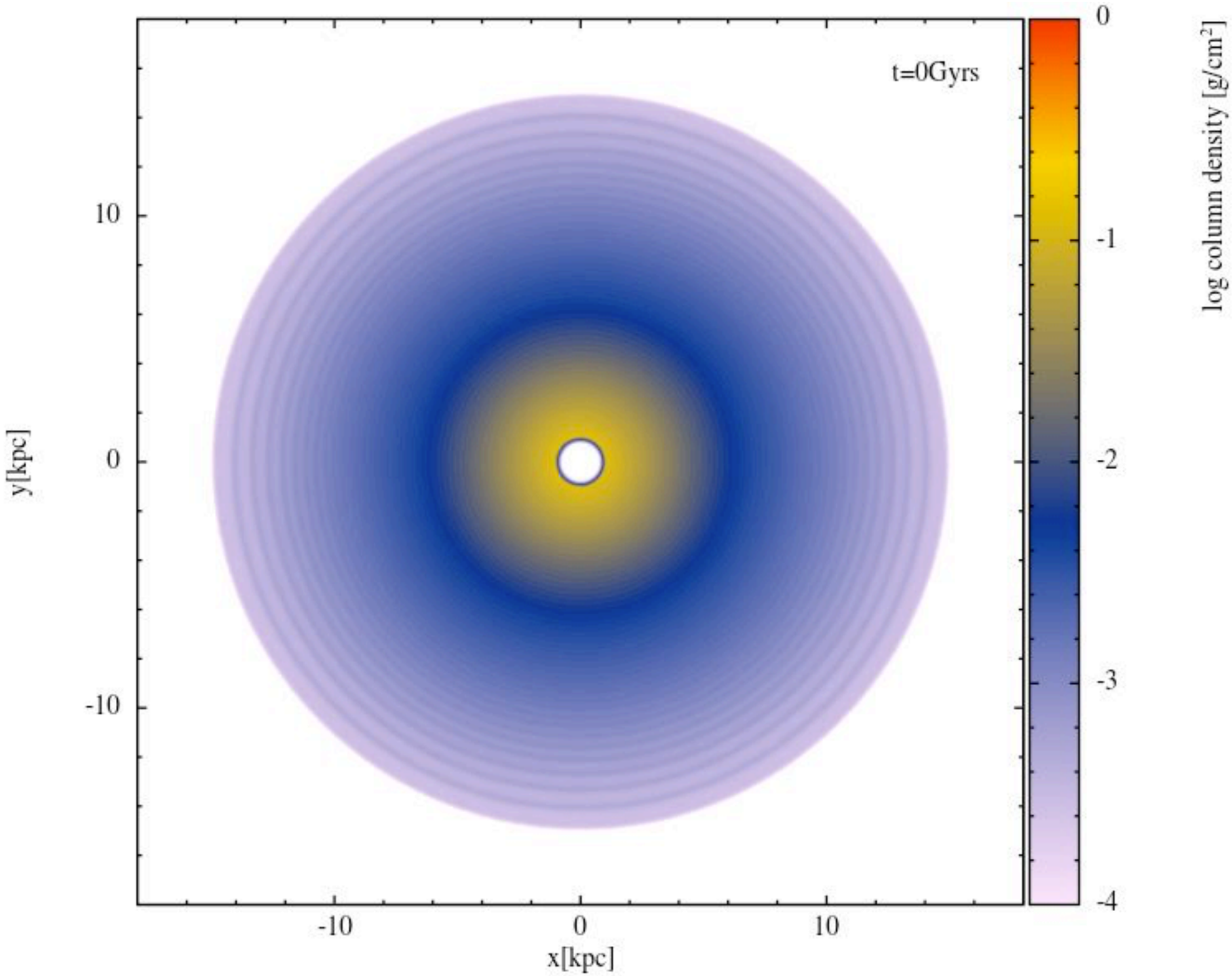
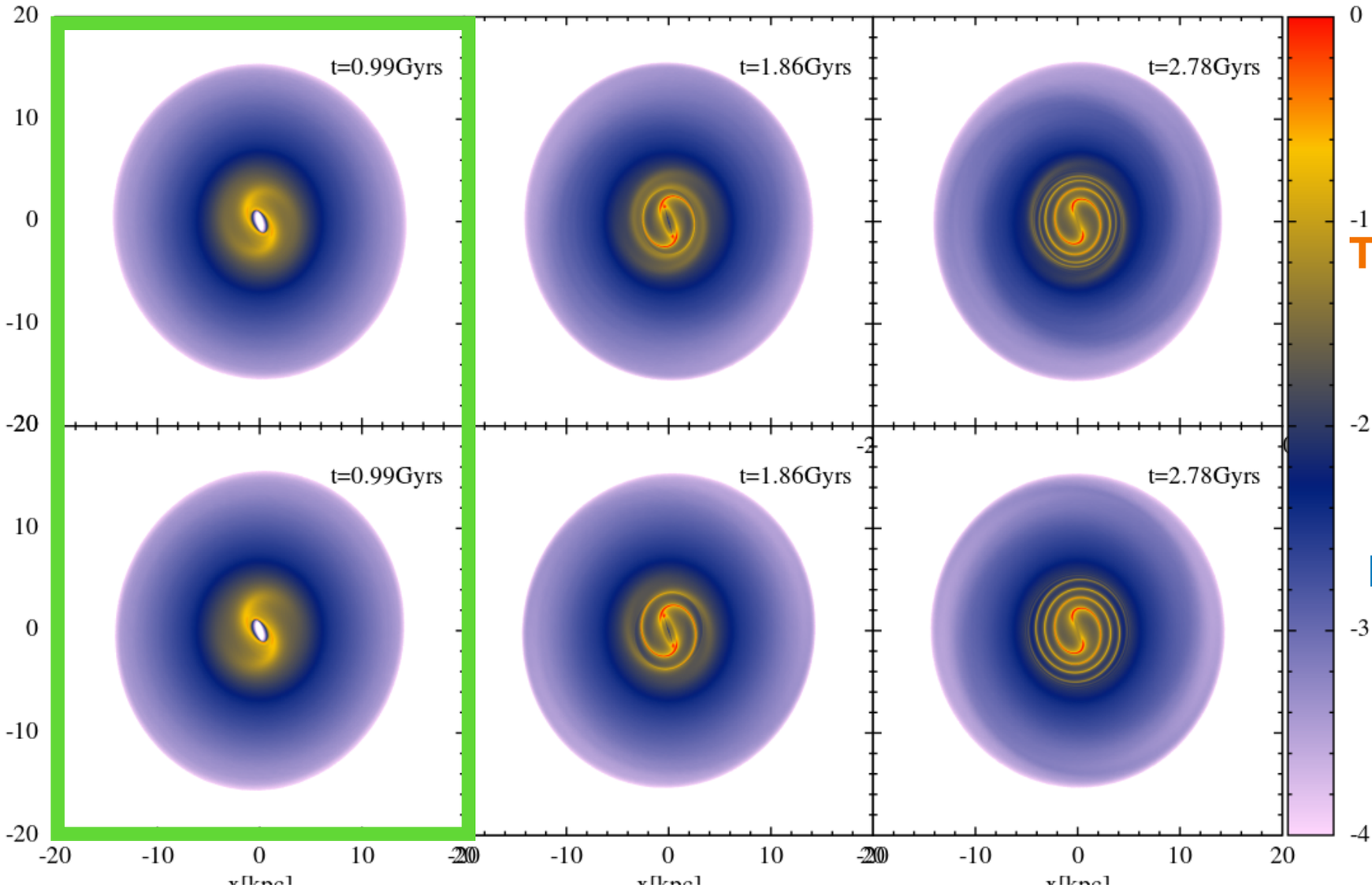
Bulge-free Halo !



Triaxial Dark Matter Halo

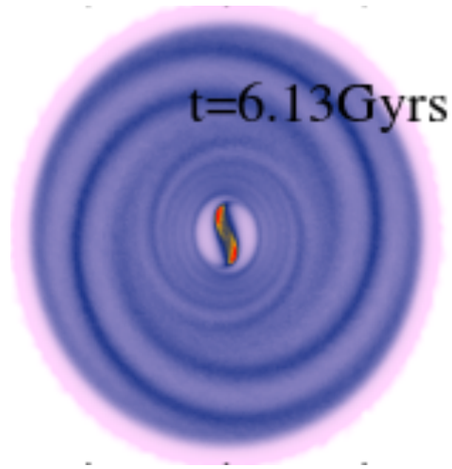
Exponential disc without bulge + High Resolution N = 10^7



Linear
q = 0.1
Tg = 1Gyr

Polynomial
q = 0.1
Tg = 1Gyr

Flat disc without bulge + High Resolution N = 10^7



T_p **$1T_r$** **$2T_r$**

Induced arms are highly sensitive to disc parameters.

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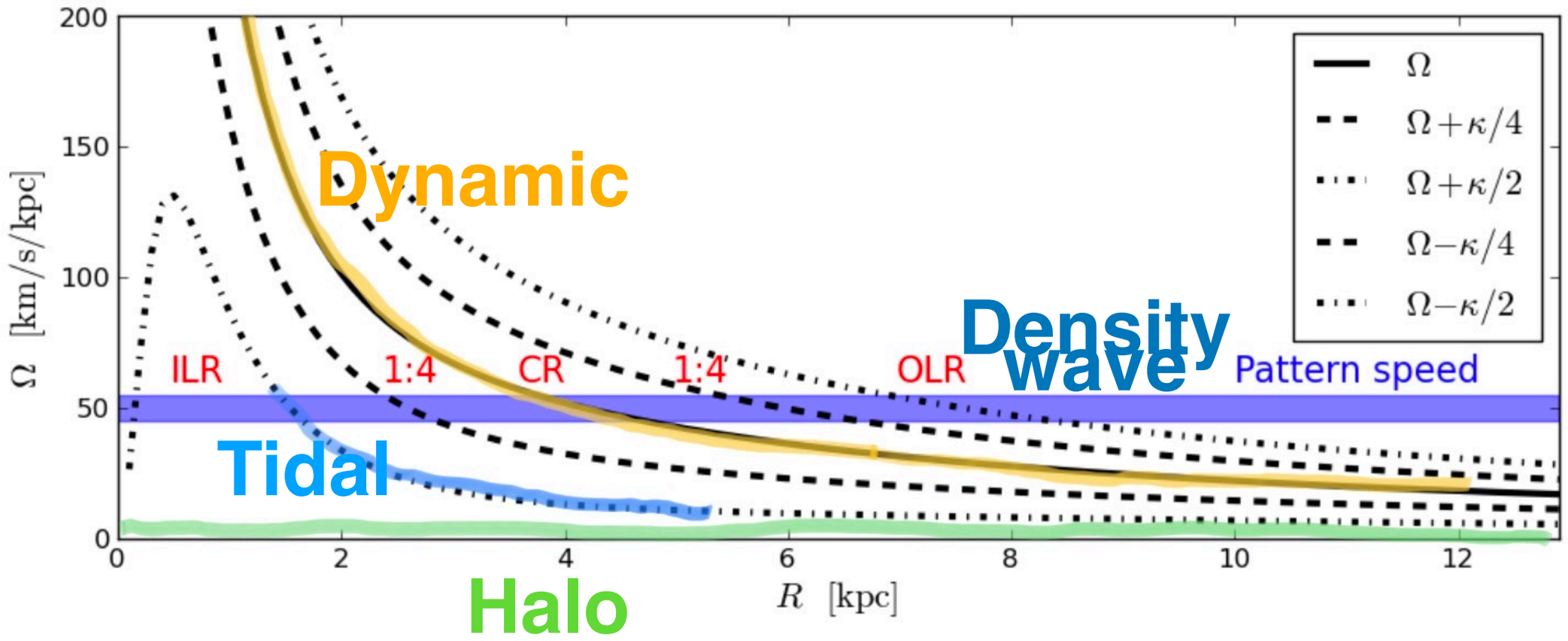
Appendix



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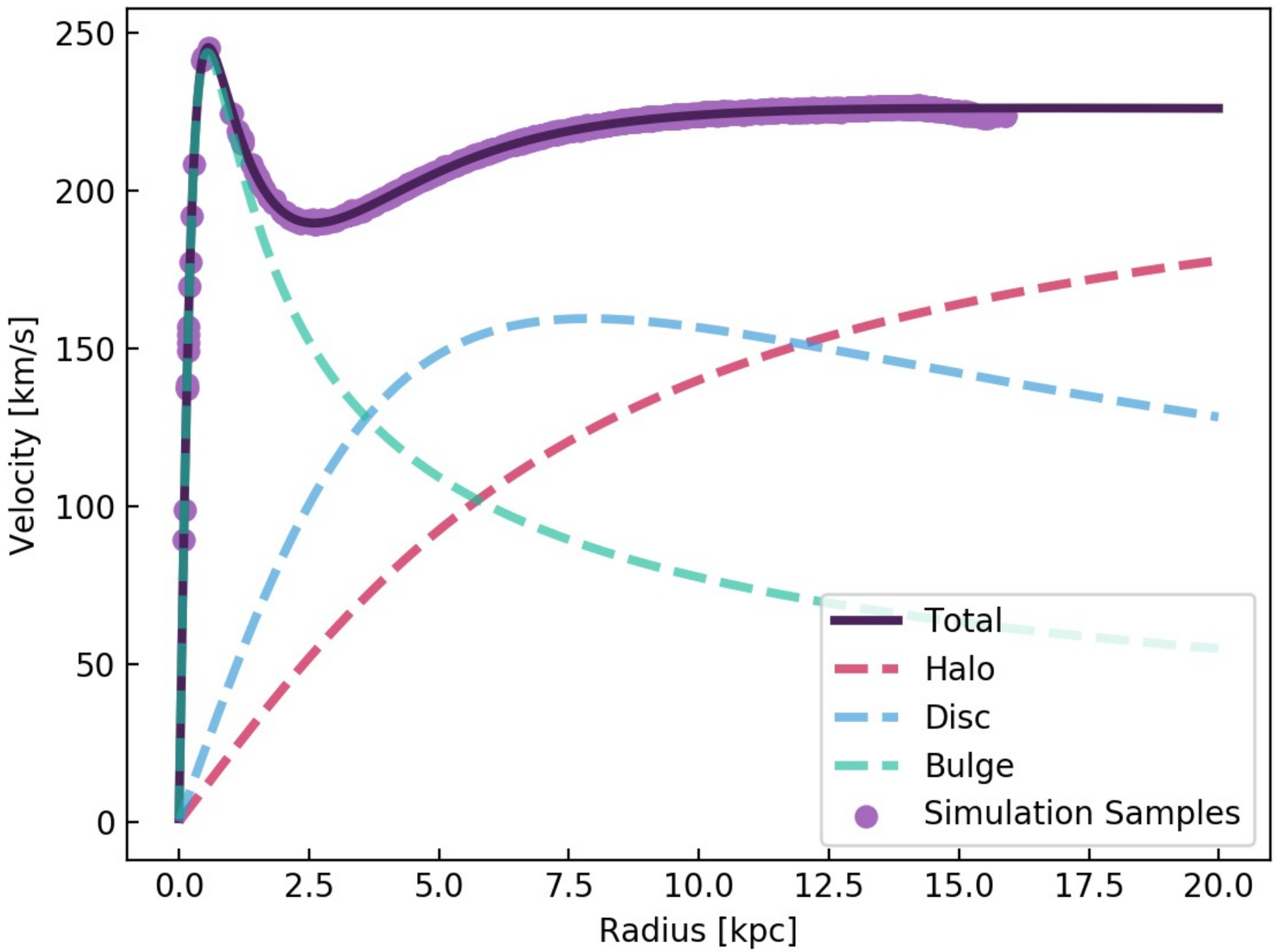
Rotation Curve



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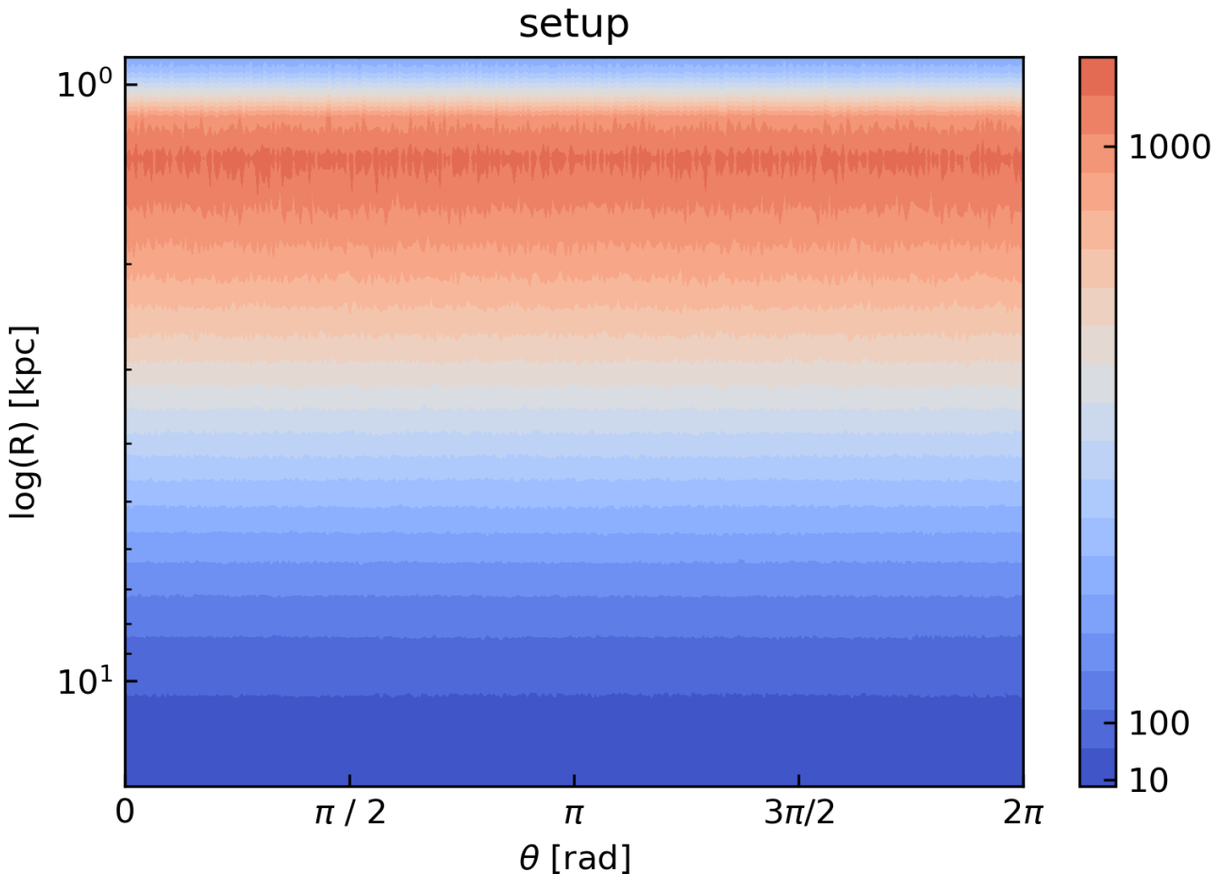
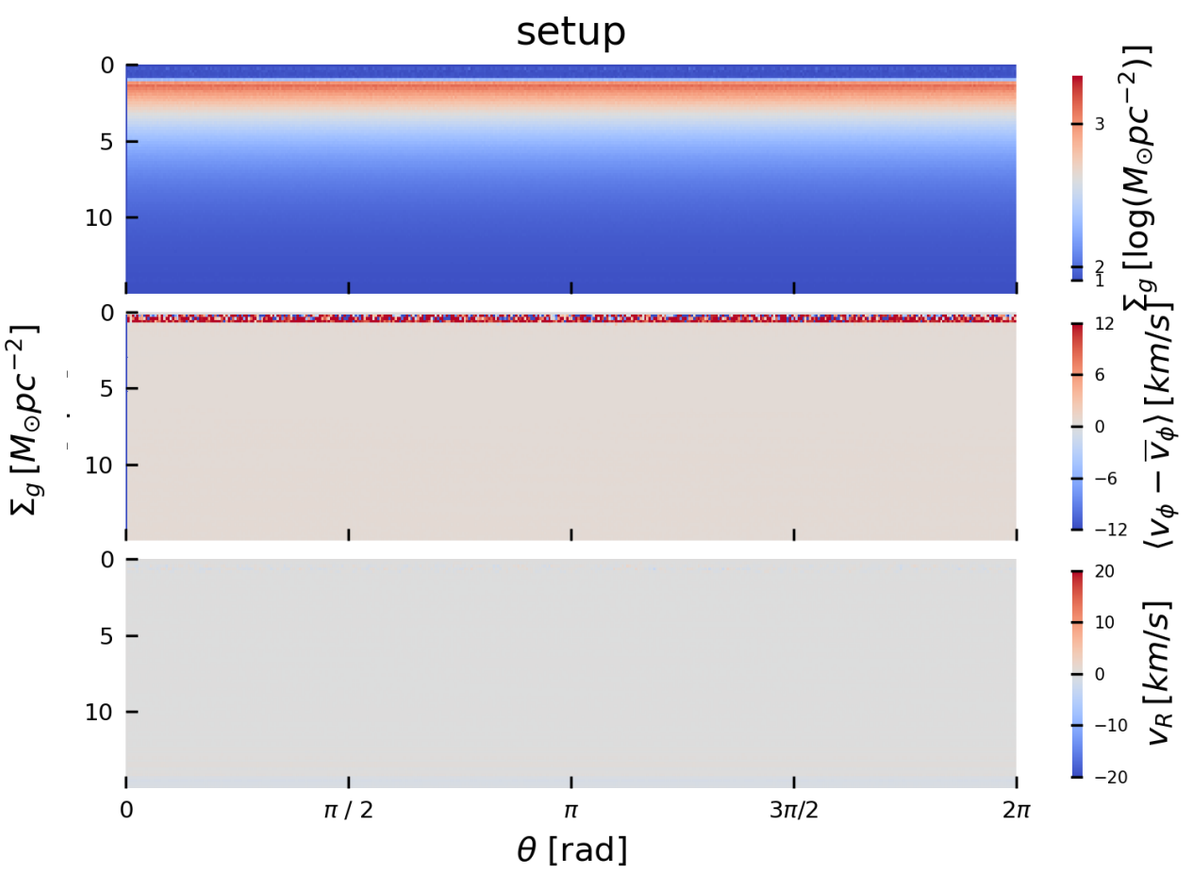
Appendix

Initial Setup





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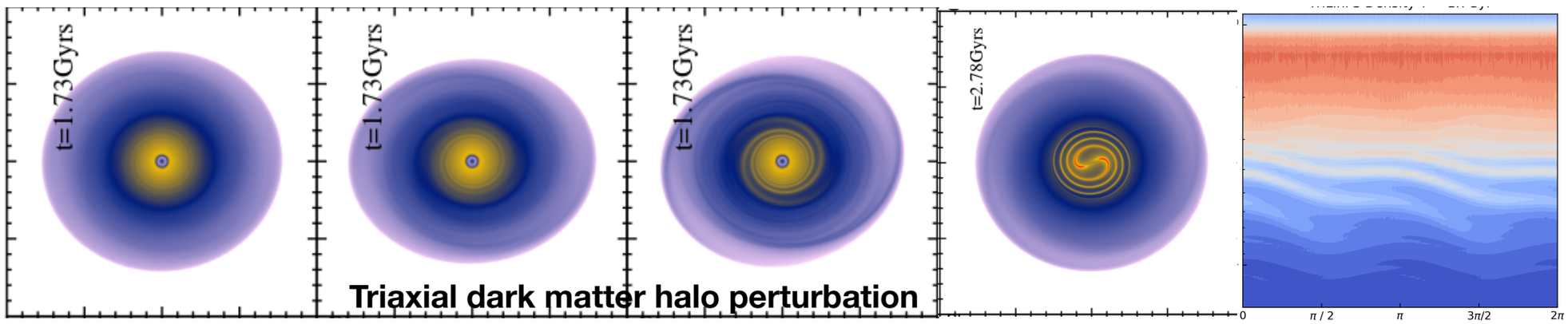
Spiral Arms In Gaseous Galactic Discs Driven By Different Mechanisms

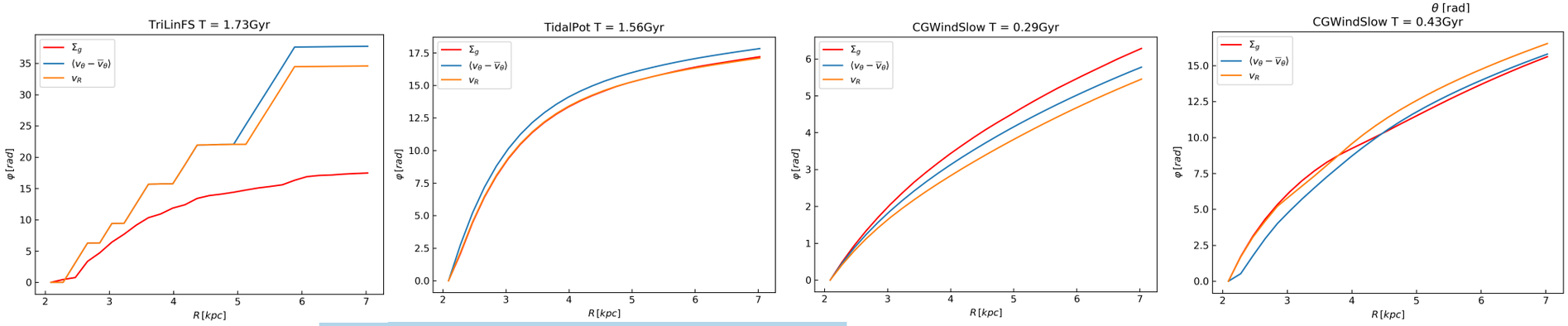
Ying Zhang **Advisor: Dr. Alex Pettitt**

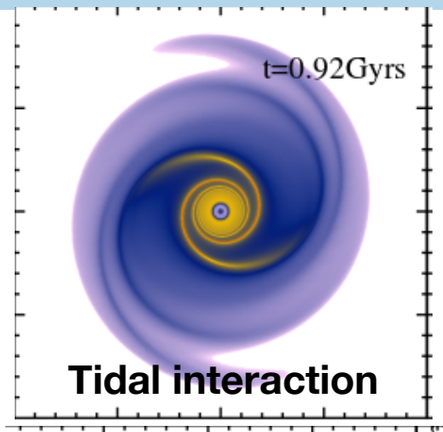
Abstract

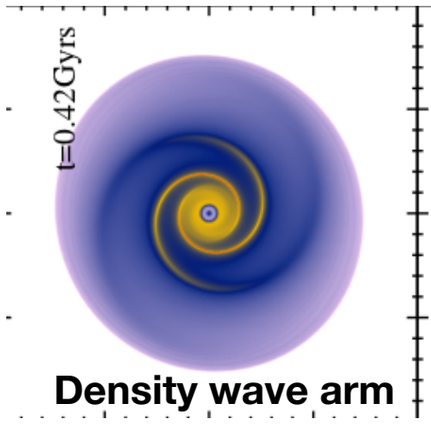
Though various spiral structures and its formation mechanisms have been investigated since long before, but hardly gas dynamics had been compared between different candidate theories and particularly, spirals induced by triaxial dark halos is least learned. we have implemented various galactic perturbations and performed simulations to investigate first, how gas disc responds to a adiabatically grown triaxiality of dark matter halo and second, comparing the dynamic responses of gas to different analytical galactic spiral perturbations in a MW like galaxy including density wave arms, dynamic arms, tidal interaction and triaxial dark matter halo.

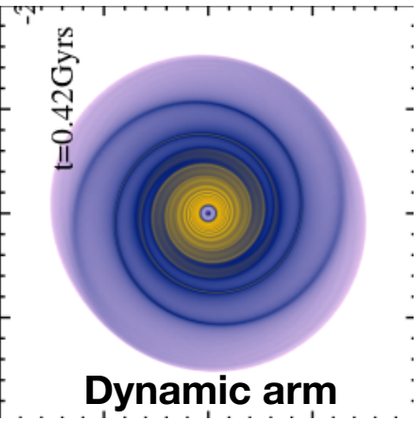
We have implemented a triaxial halo with various growth functions for a Milky Way-like galaxy and a bulge-free galaxy MW -like discs display notable arms within one rotational period after the halo is fully switched-on when the halo's triaxility is strong and turned on quickly. Moreover, the induced spirals are not logarithmic. However, for bulge-free discs, leading arms appear in the inner disc region.











Fourier decomposition :

$$I(r) = 1 + \sum_{m=1}^{\infty} A_m(r)\cos m[\phi - \phi_m(r)]$$

$$\phi_2(r) - \phi_2(r_0)$$

We adapt Fourier decomposition to plot offset diagrams to show the difference within phase changes of density, averaged azimuthal velocity and radial velocity.

Conclusions

1. Spirals generated by triaxial dark matter halos are very sensitive to the specific galaxy disc parameter, such as surface density and distribution, rotation curve etc.

2. Both of the two-armed spirals induced by triaxial dark matter halo and tidal component are not logarithmic. Together with the difference in relative phases of the velocities and density peaks, this could be a diagnostic of the nature of spiral arms in real observed galaxies.