The destiny of Tidal Dwarf Galaxies

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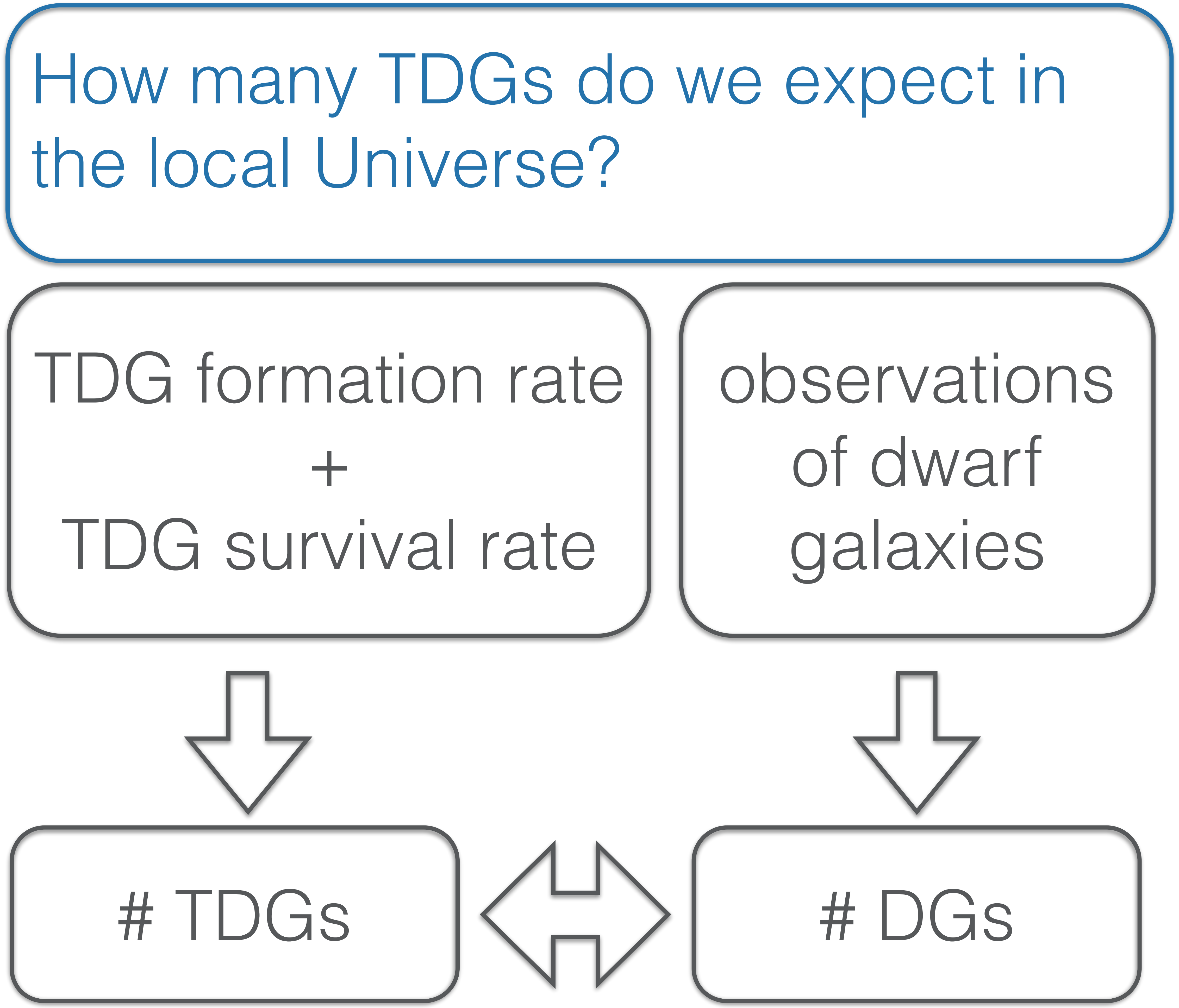
Universiteit Leiden

Motivation



#TDGs / galaxy interaction	Typical TDG lifetime	#TDGs/#DGs	Reference
1-2	10 Gyr	1	Okazaki & Taniguchi (2000)
0.1-0.2	10 Gyr	0.1	Bournaud & Duc (2006)
0.8	1 Gyr	0.1	Bournaud & Duc (2006)
0.33	10 Gyr	0.06	Kaviraj et al. (2012)

Motivation

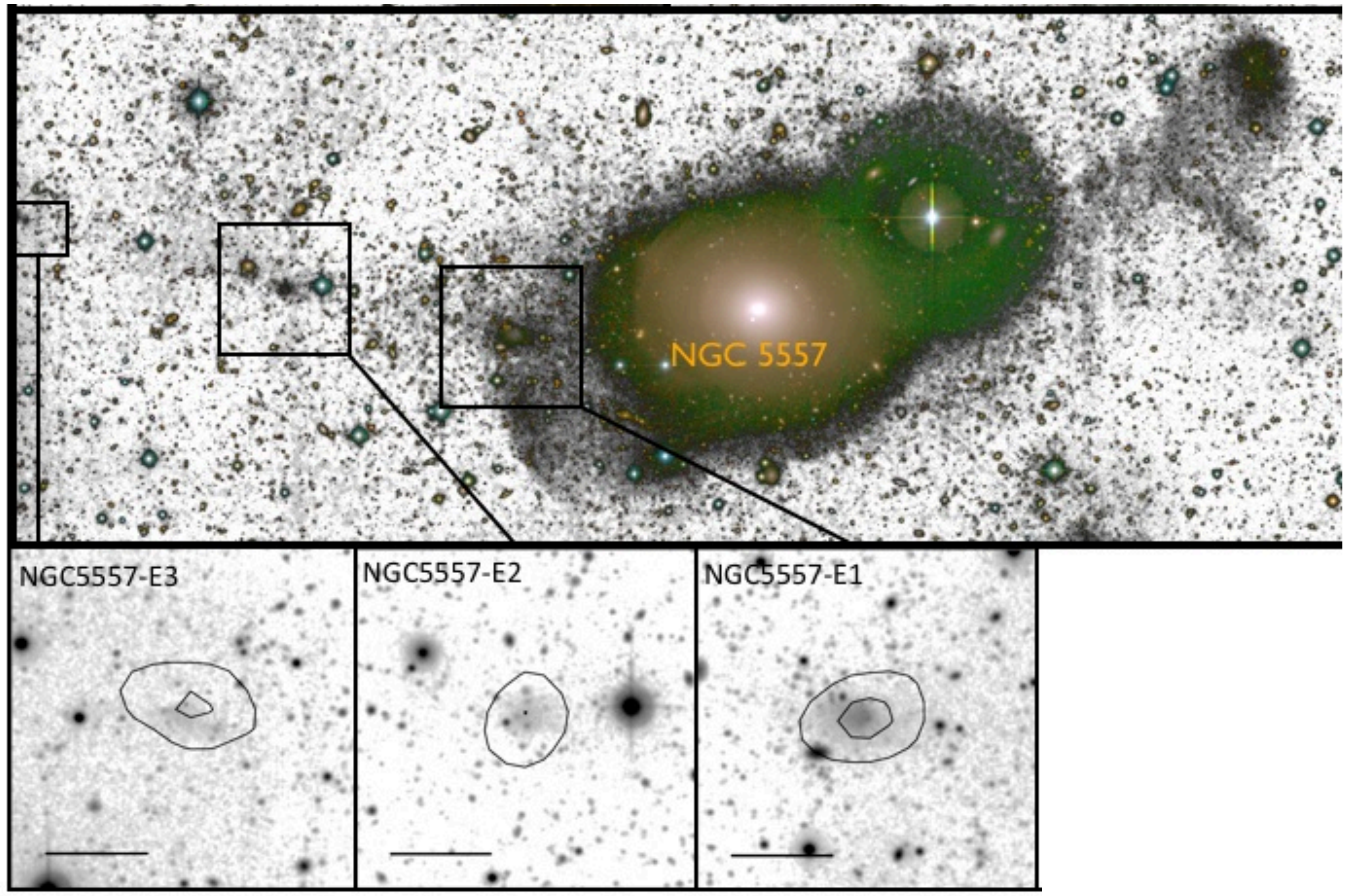
How many TDGs do we expect in the local Universe?

TDG formation rate
+
TDG survival rate

observations of dwarf galaxies

TDGs ⇔ # DGs

Figure: Duc et al. (2014)



Estimated age: 4 Gyr (oldest TDG so far)

Motivation

Study the survivability of TDGs

How many TDGs do we expect in the local Universe?

TDG formation rate
+
TDG survival rate

observations of dwarf galaxies

TDGs ⇔ # DGs

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Method: The FLASH Code

Flash v3.3

- Adaptive mesh refinement
- Hydro solver
- Multi-grid solver for self-gravity
- Excellent scaling for parallel computing
- Leapfrog integration for particles

we need more for TDGs:

- Initial conditions
- External tidal field
- External time-variable wind (ram pressure stripping)
- Metal-dependent radiative cooling
- Star formation
- Stellar evolution
- Stellar feedback

Results I

Study the first response of the TDG to different stellar feedback scenarios

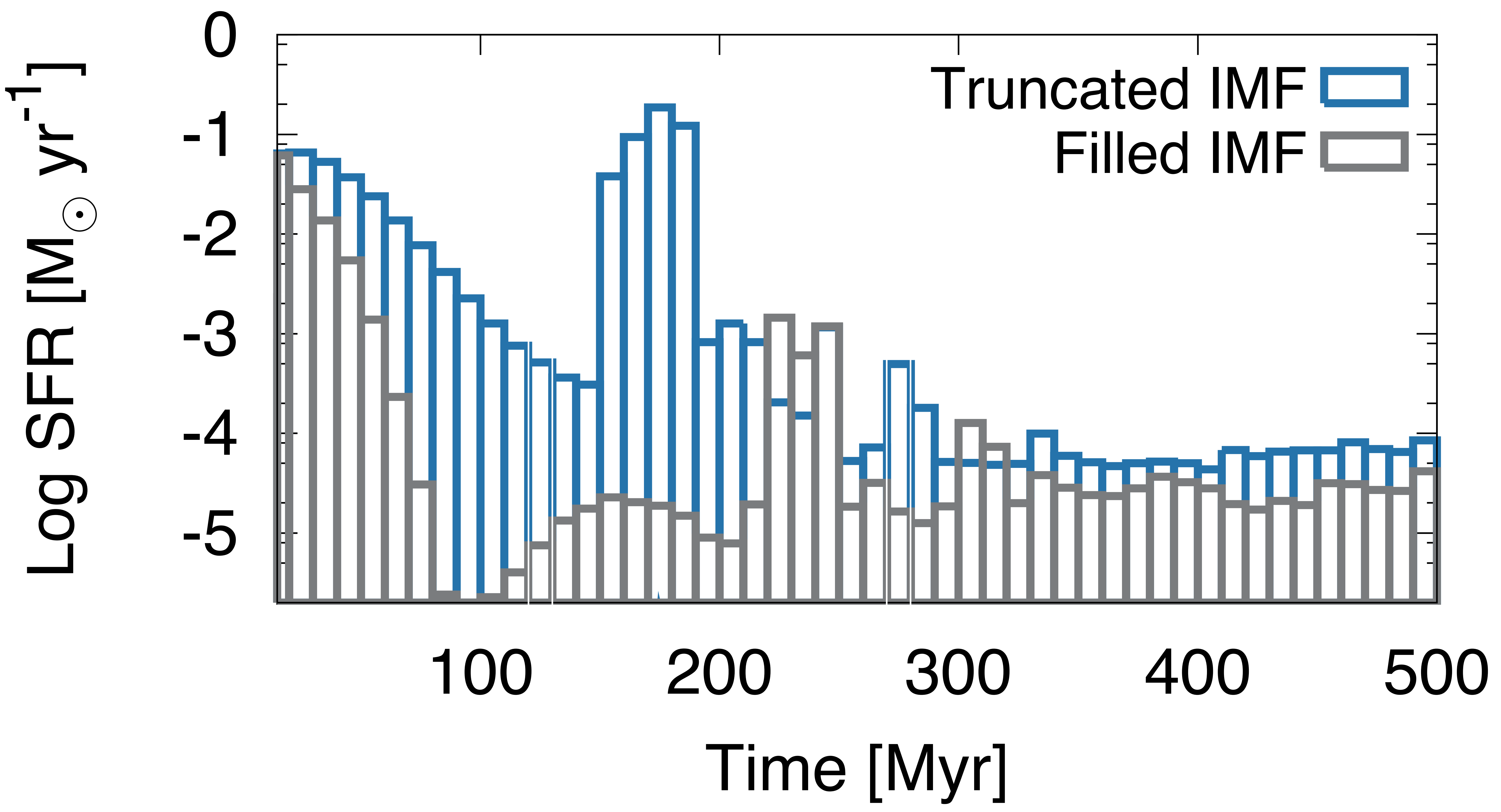
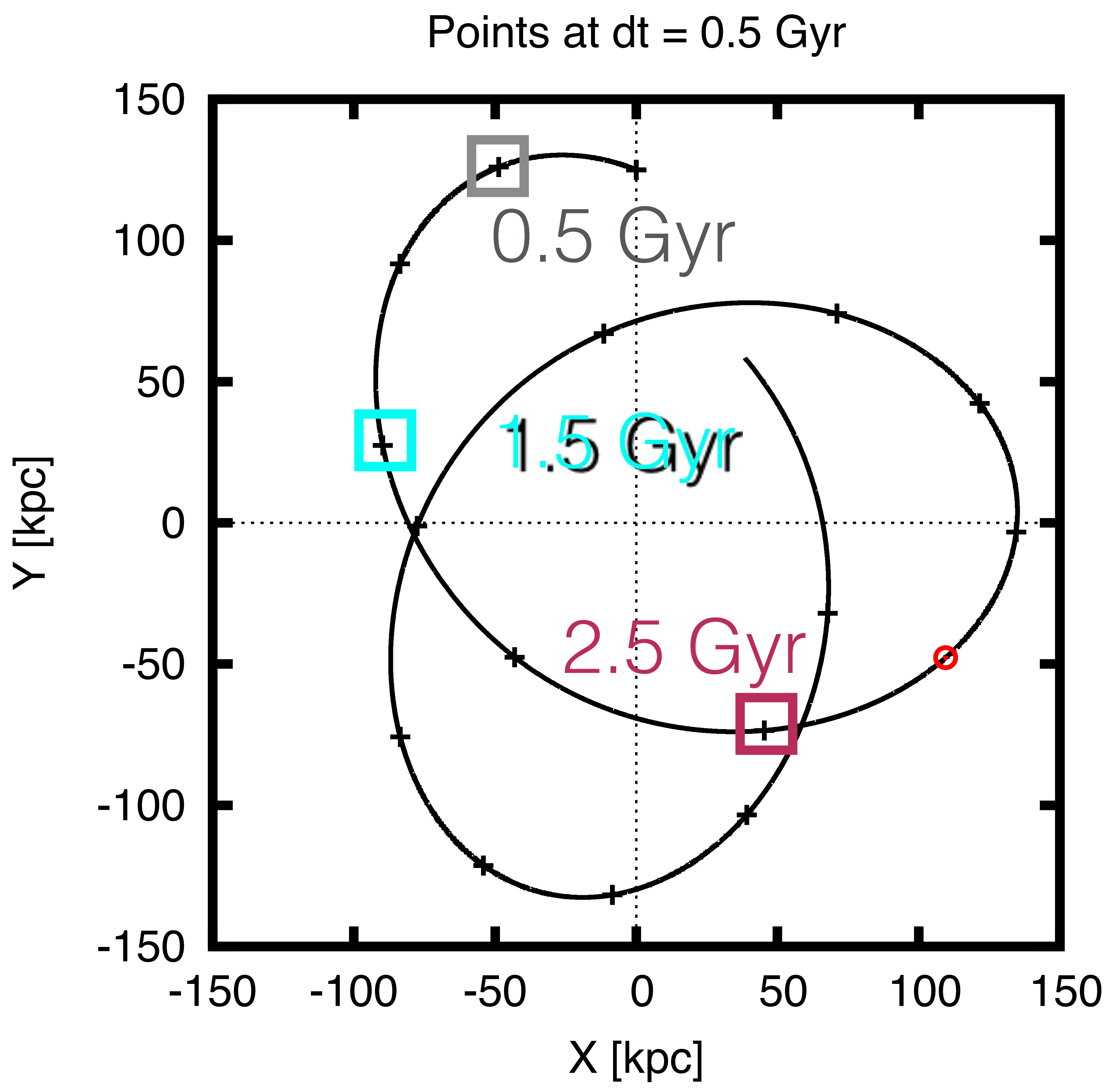


Figure: **Ploeckinger** et al. (2014)

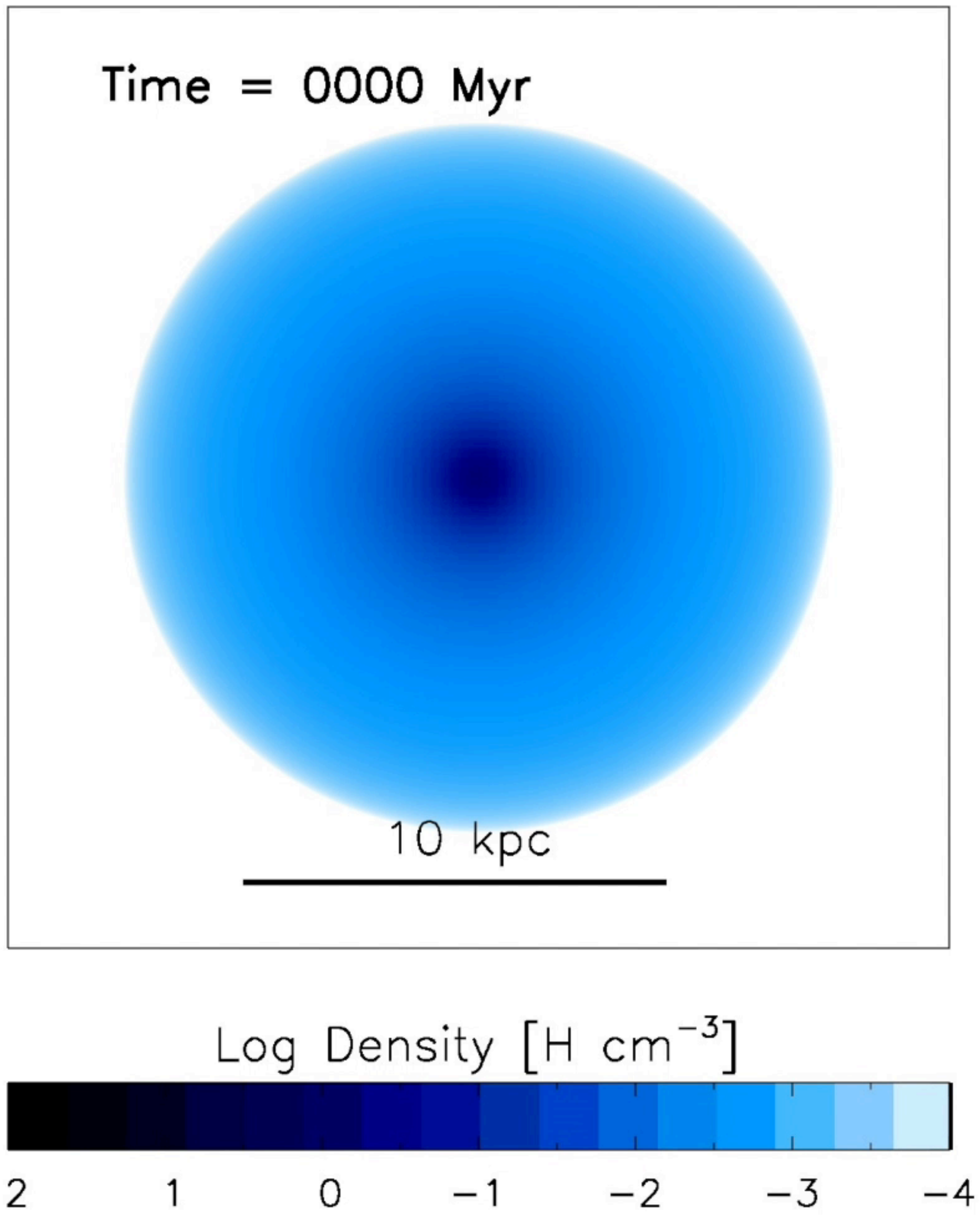
Results II

Study the long-term evolution of TDGs

Orbit:



Initial pro-grade rotation



Figures: **Ploeckinger** et al. (2015)

Results II

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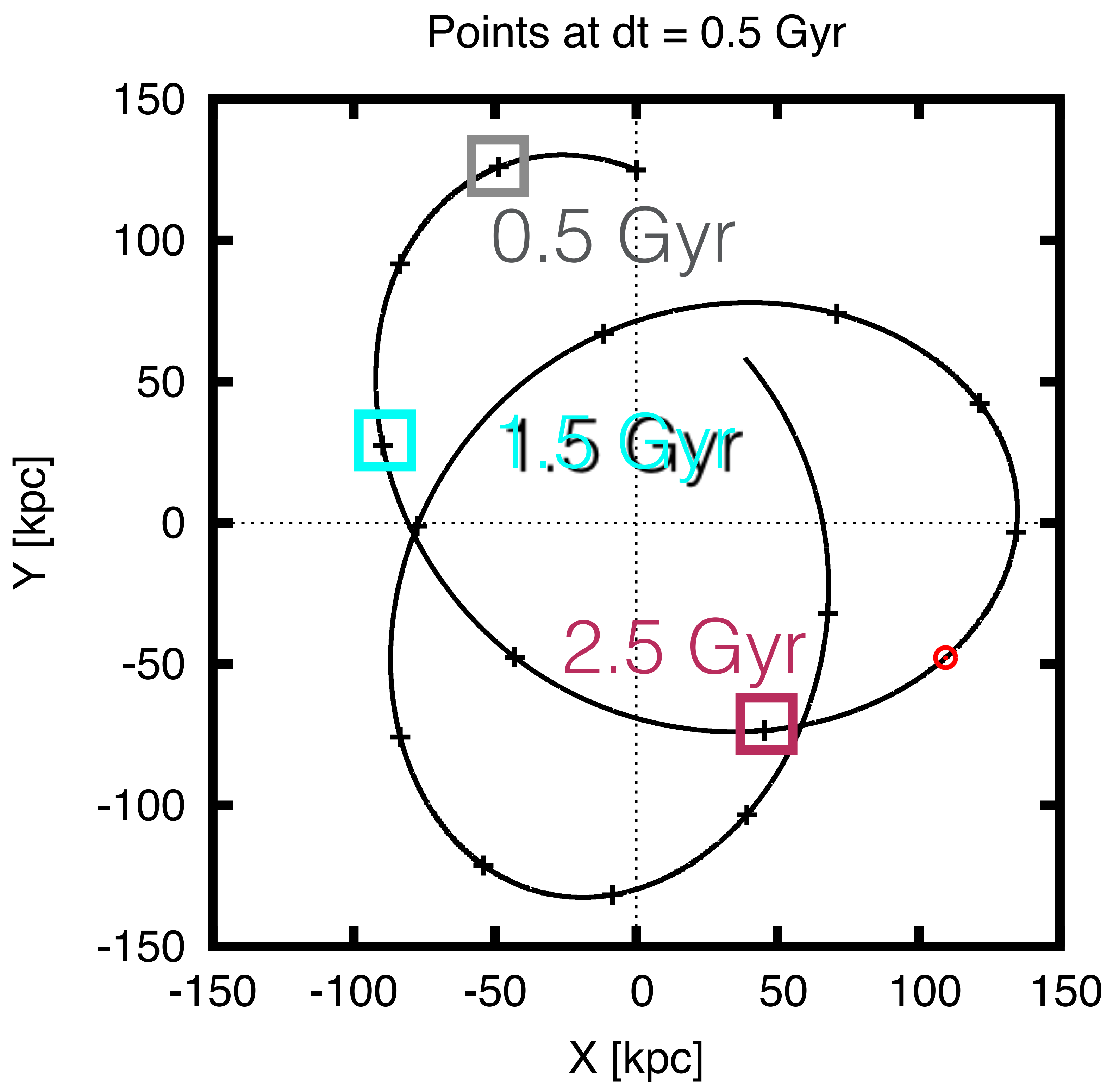

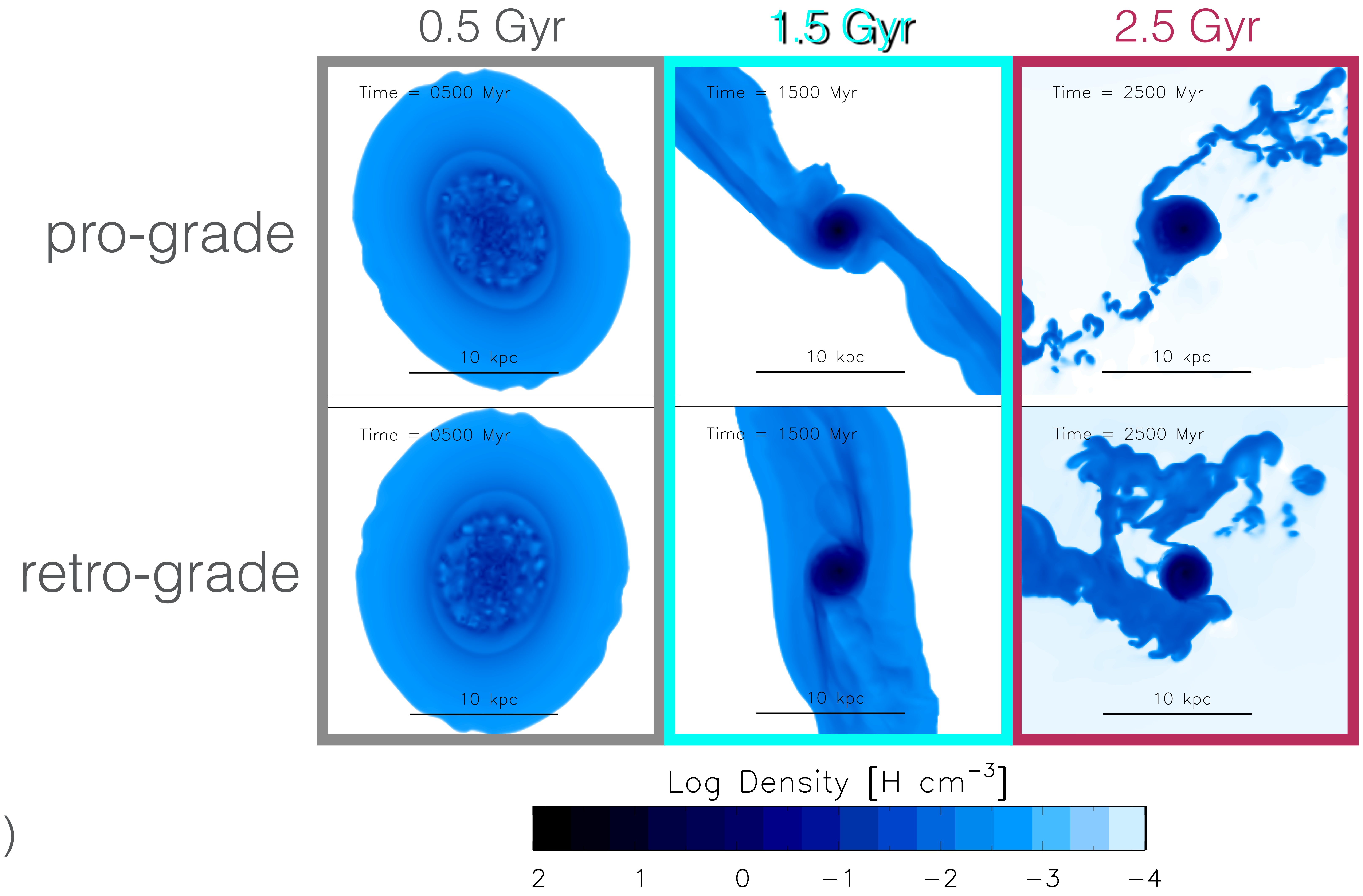

Figures: **Ploeckinger** et al. (2015)

Results II

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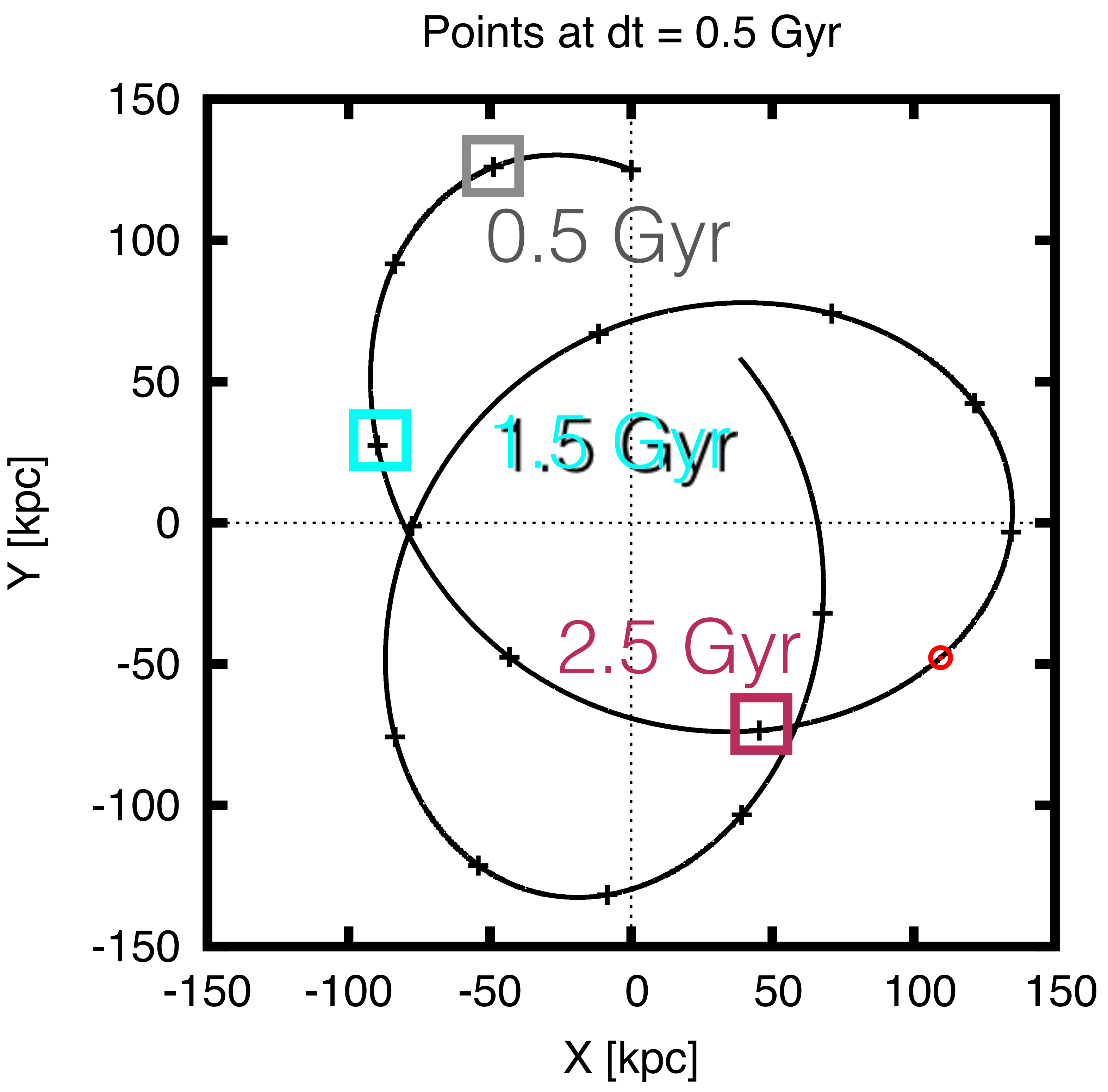
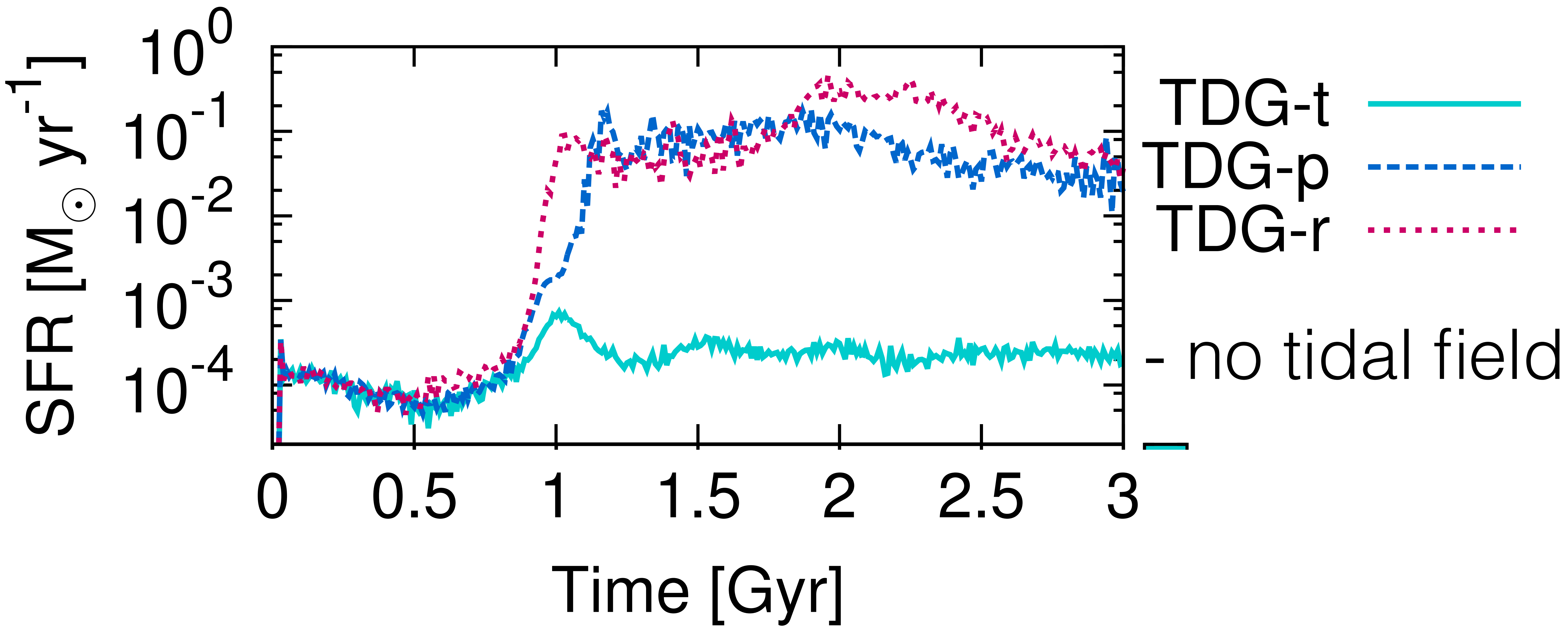


Star formation rate:



Figures: **Ploeckinger** et al. (2015)

Problems…

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Idea

Isolated dwarf galaxies
in DM halos:

Long-time survival:
undoubted

Tidal dwarf galaxies
in a tidal field:

Long-time survival:
questioned

Completely different approach

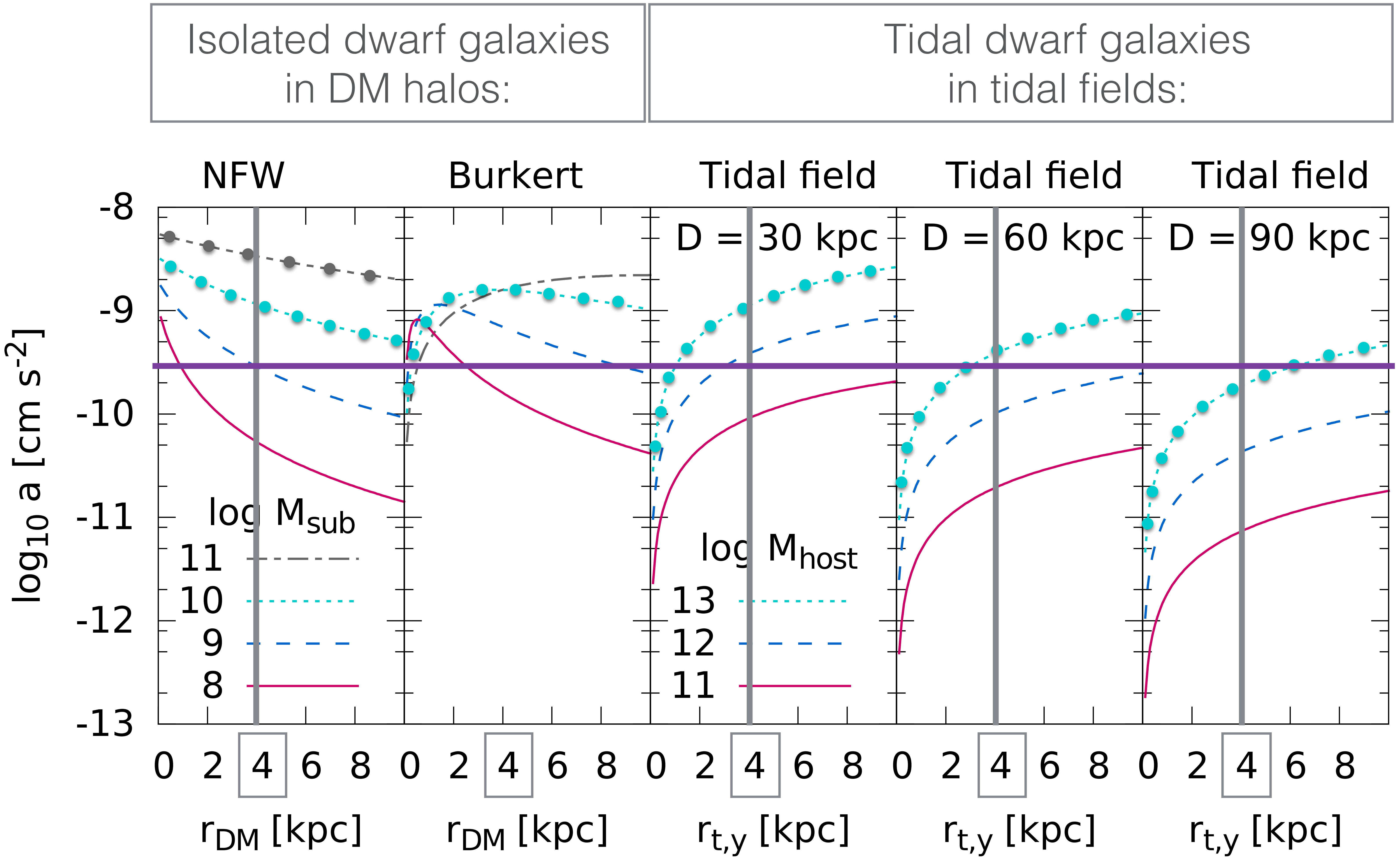
How compressive is the tidal field compared to a DM halo?

or:

"Tides or dark matter halos:
Which ones are more attractive?"

Ploeckinger (subm.)

“Tides or dark matter halos: Which ones are more attractive?”



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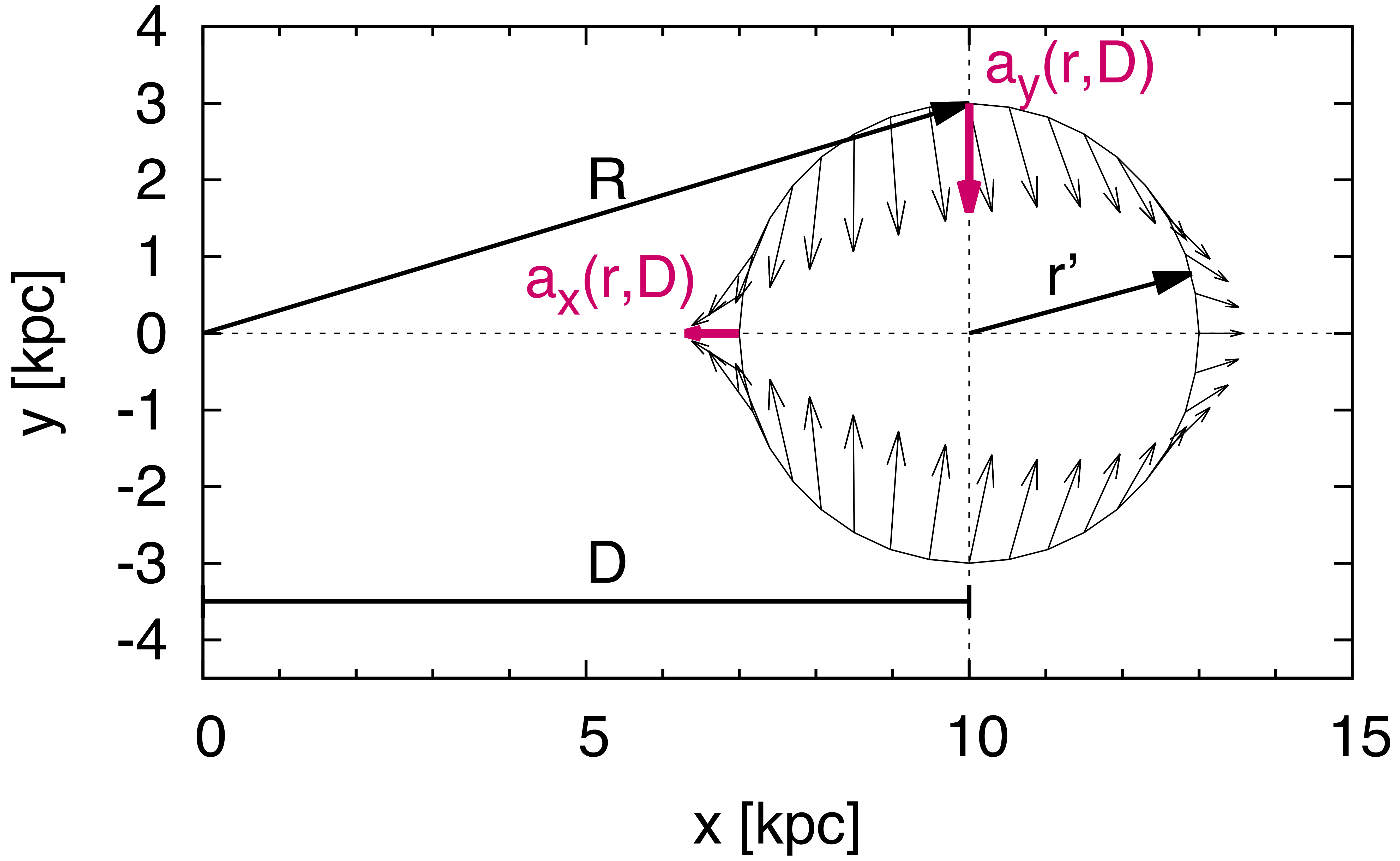


$$\Phi_{\mathrm{NFW}}(R) = -\frac{G\rho_{0,h} r_{0,h}^3}{R} \cdot \log(1 + R/r_{0,h})$$

Tidal field:

$$|a_y| = \frac{4\pi G \rho_{0,t} r_{0,t}^3}{\sqrt{1+\left(\frac{D}{r}\right)^2}} \frac{(r_{0,t}+R)\log\left(\frac{r_{0,t}+R}{r_{0,t}}\right) - R}{R^2(r_{0,t}+R)}$$

$$\text{with :} \quad R = \sqrt{D^2 + r^2}$$

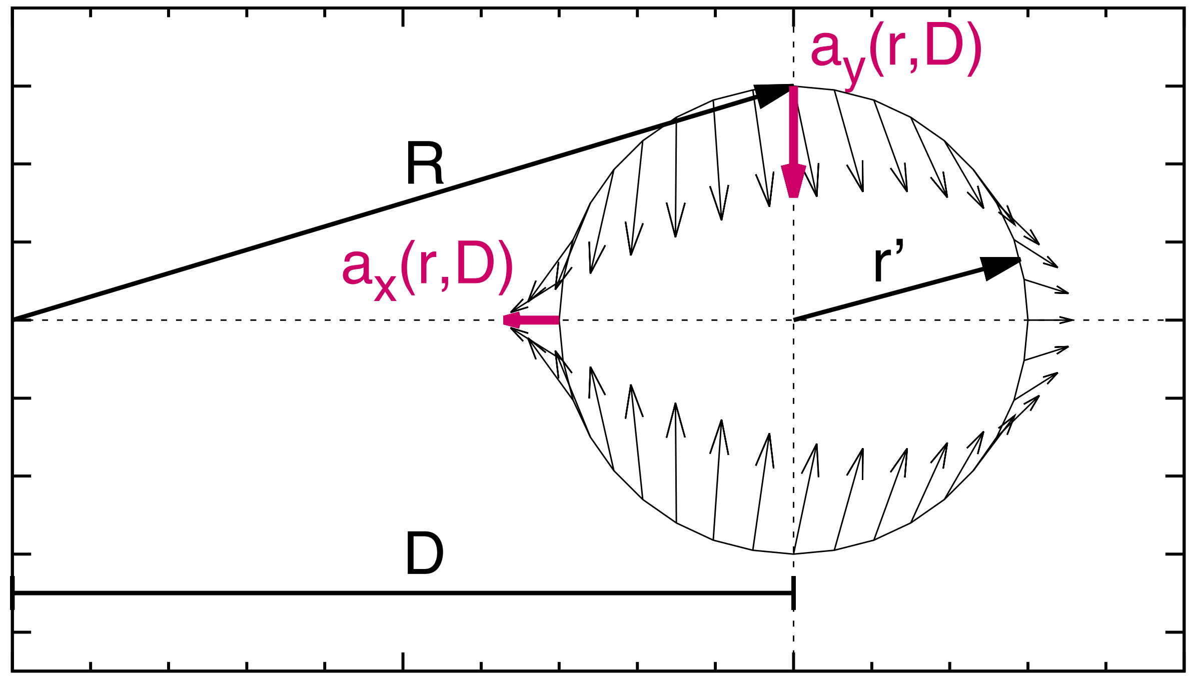
Isolated DM halos:

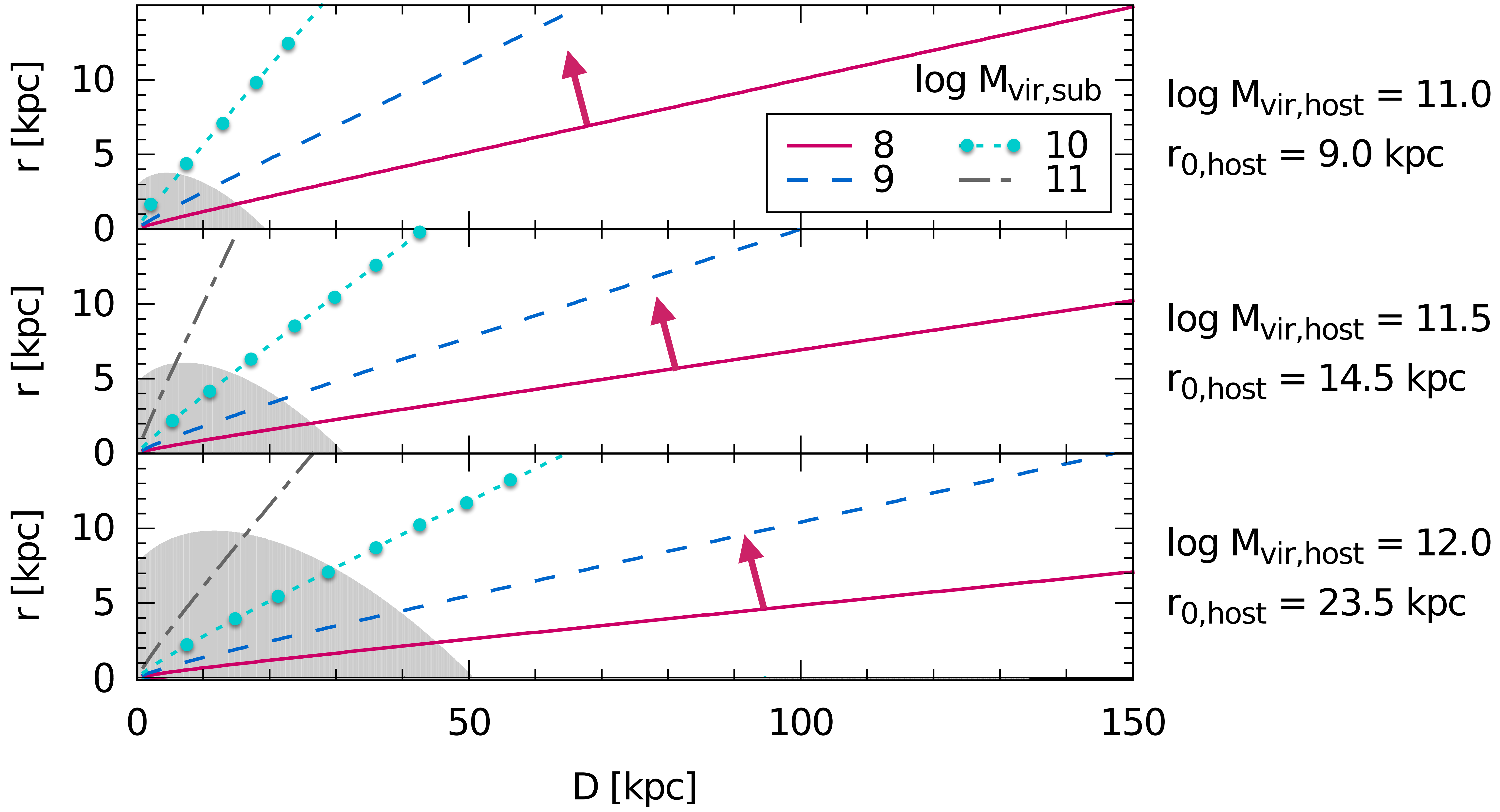
$$|a_r| = 4\pi G \rho_{0,d} r_{0,d}^3 \frac{(r_{0,d}+r)\log\left(\frac{r_{0,d}+r}{r_{0,d}}\right) - r}{r^2(r_{0,d}+r)}$$

Ploeckinger (subm.)

"Tides or dark matter halos: Which ones are more attractive?"

$$|a_y/a_r| = |a_y/a_r|(M_{\rm vir,host}, M_{\rm vir,sub}, D, r)$$





Ploeckinger (subm.)

"Tides or dark matter halos: Which ones are more attractive?"

Survival of TDGs is supported by the tidal field

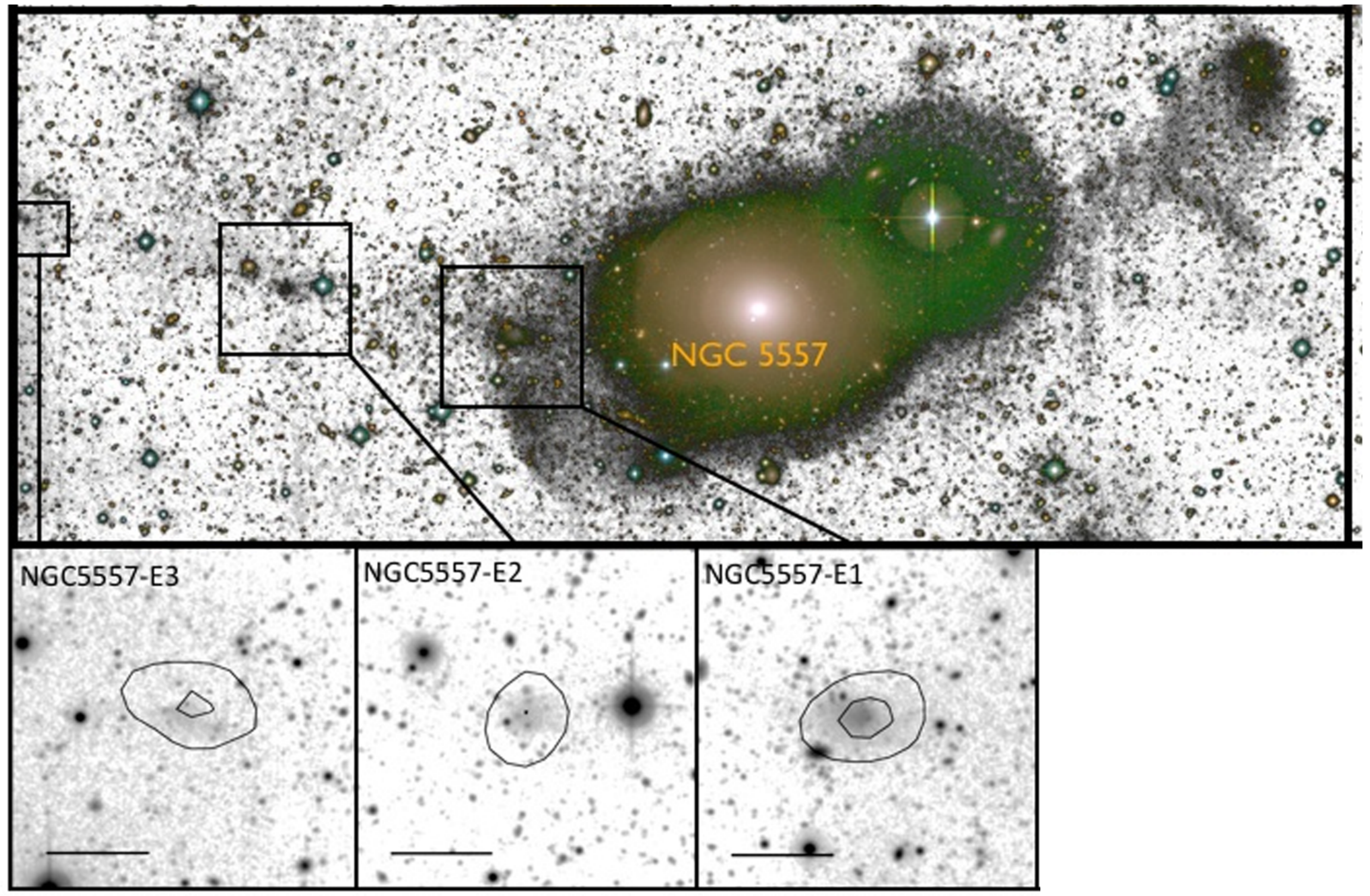
Host galaxy → D

Inner region problematic:
Dynamical friction
Tidal radius

Tidal field decreases

"Tides or dark matter halos: Which ones are more attractive?"

Application I - NGC 5557



$$|a_y/a_r| = |a_y/a_r|(M_{\mathrm{vir,host}}, M_{\mathrm{vir,sub}}, D, r)$$

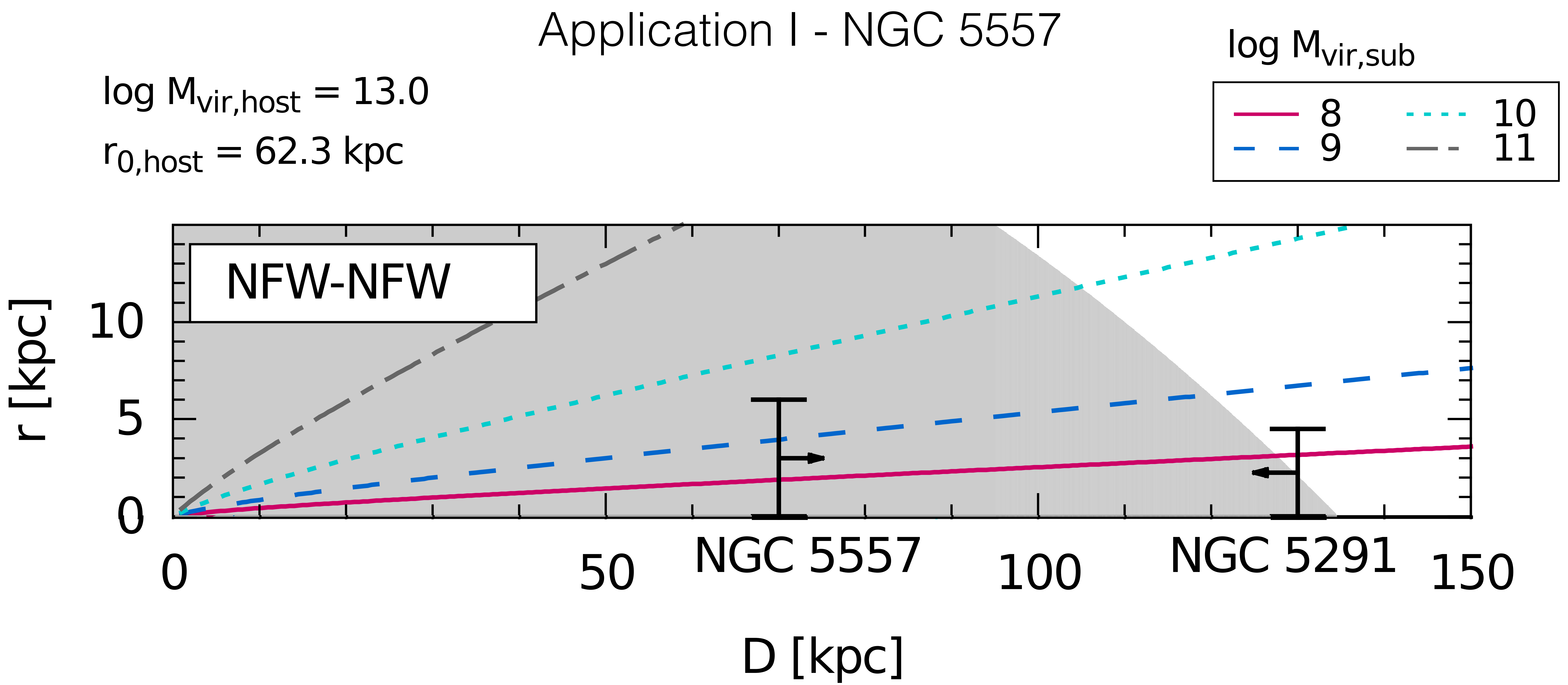
$v_{\mathrm{max}} = 340\,\mathrm{km\,s^{-1}}$ (Capellari et al. 2013)

$M_{\mathrm{vir,host}} \approx 10^{13}\,\mathrm{M_\odot}$

$D > 70\,\mathrm{kpc}$

Duc et al. 2014 Estimated age: 4 Gyr

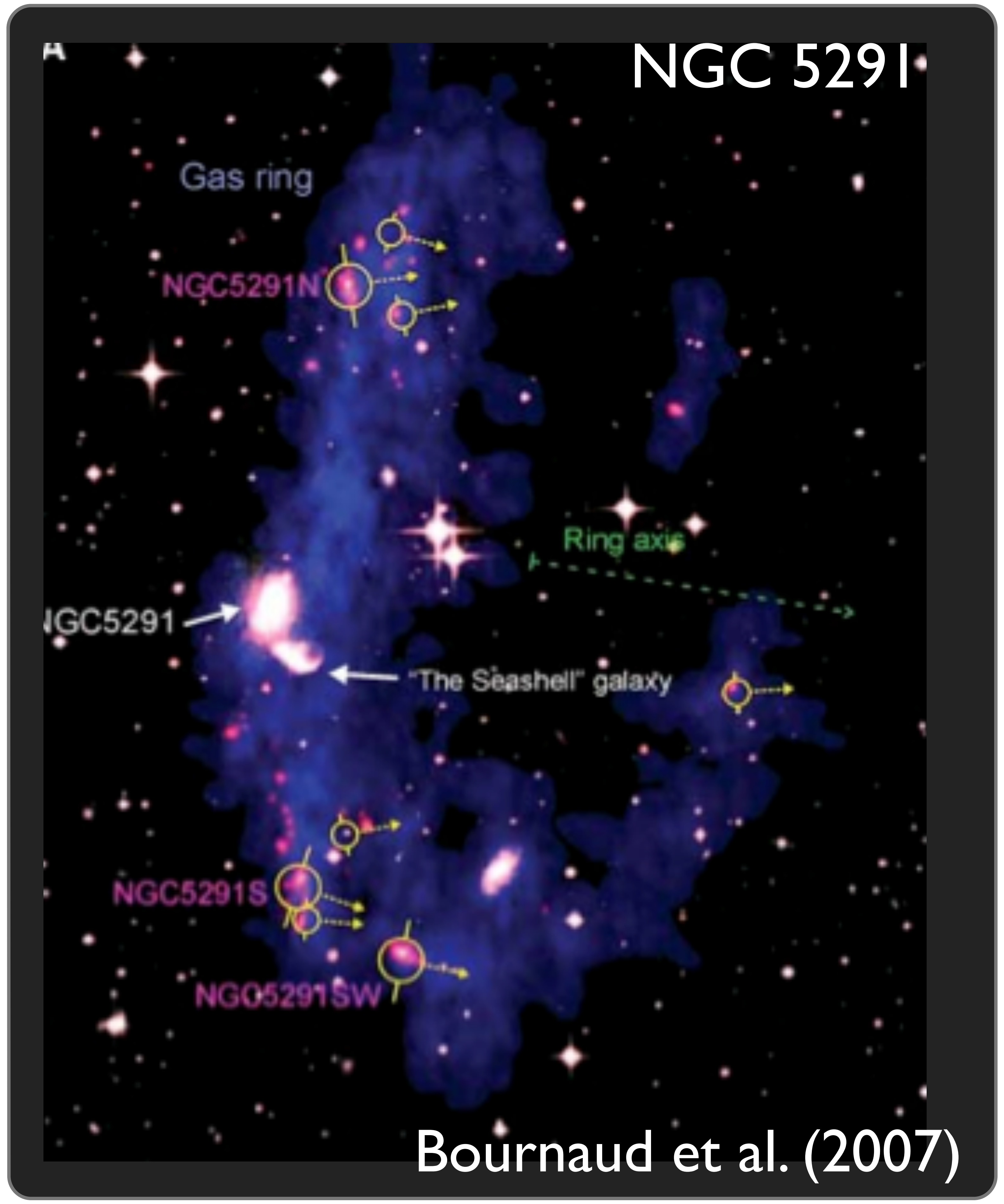
"Tides or dark matter halos: Which ones are more attractive?"



Ploeckinger (subm.)

"Tides or dark matter halos: Which ones are more attractive?"

Application II - NGC 5291



$$|a_y/a_r| = |a_y/a_r|(M_{\rm vir,host}, M_{\rm vir,sub}, D, r)$$

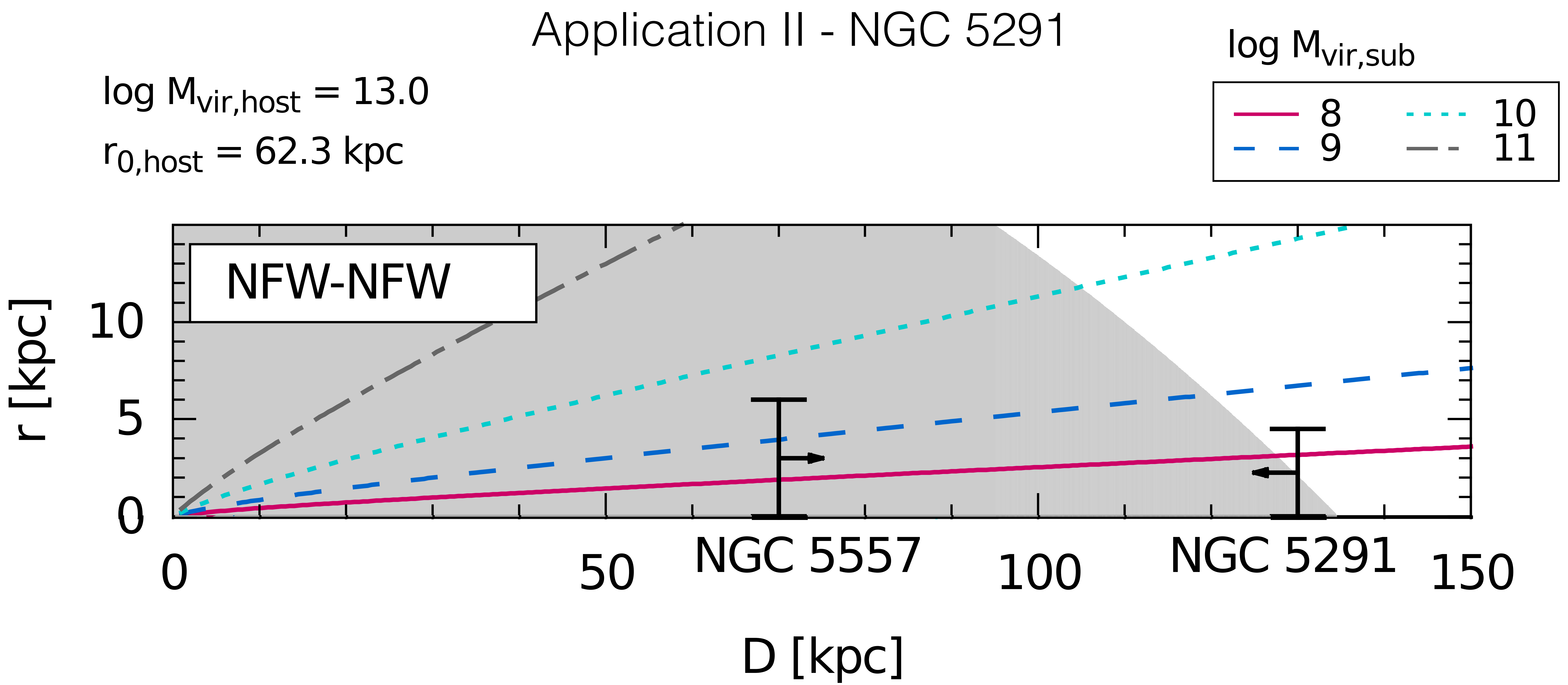
$w_{50} = 637\,{\rm km\,s^{-1}}$ (Koribalski et al. 2004)

$M_{\rm vir,host} \approx 10^{13}\,{\rm M_\odot}$ $D \approx 130\,{\rm kpc}$

Missing dynamical mass should be around

$$1 - 2 \times 10^{9}\,{\rm M_\odot}$$

"Tides or dark matter halos: Which ones are more attractive?"



Ploeckinger (subm.)

“Tides or dark matter halos: Which ones are more attractive?”

Quick and easy method to:

- explore regions where long-term survival of TDGs is supported by the tidal field (goldilock zone)
- explaining the old age of individual TDGs
- predict which TDGs are more likely to survive

Mathematica notebooks

https://sites.google.com/site/sylviaploeckinger/tidal-dwarf-galaxies/analytical-work-on-tdgs

All .nb contain:
- full derivation of all equations
- hands-on examples

```
In[14]:= rhoc = 3 * H0 ^ 2 / (8 * Pi * G);
alpha = 1.49809;
beta = -0.02499;
gamma = 0.0056;
ct =
  10 ^
   (alpha + beta * Log10[Mvirt] *
      (1 + gamma * (Log10[Mvirt]) ^ 2));
(* ct from Correa et al. 2015 *)
R[r_] := Sqrt[Dist ^ 2 + r ^ 2];

(* characteristic over-density of each halo: *)
deltac[c_] := 200. / 3. * c ^ 3 / (Log[1 + c] - c / (1 + c));

(* y-component of the tidal field at (D,r): *)
ay[r_] := G * rho0t * r0t ^ 3 / Sqrt[1 + (Dist / r) ^ 2] *
  ((r0t + R[r]) * Log[(r0t + R[r]) / r0t] - R[r]) /
   (R[r] ^ 2 * (r0t + R[r]))
Simplify[ay[r]];
(* gravitational acceleration in an NFW halo
 at a distance r *)
ar[r_] := G * rho0d * r0d ^ 3 *
  ((r0d + r) * Log[(r0d + r) / r0d] - r) / (r ^ 2 * (r0d + r))
Simplify[ar[r]];
Simplify[ay[r] / ar[r]]
```


Out[25]=

$$\frac{r^2\,(r+r0d)\,r0t^3\,rho0t\left(-\sqrt{Dist^2+r^2}+\left(\sqrt{Dist^2+r^2}+r0t\right)\mathrm{Log}\left[\frac{\sqrt{Dist^2+r^2}+r0t}{r0t}\right]\right)}{\sqrt{1+\frac{Dist^2}{r^2}}\,\left(Dist^2+r^2\right)\,r0d^3\left(\sqrt{Dist^2+r^2}+r0t\right)\,rho0d\left(-r+(r+r0d)\,\mathrm{Log}\left[\frac{r+r0d}{r0d}\right]\right)}$$

```
(* constants in cgs units *)
H0 = 67.8 * 10 ^ 5 / (3.086 * 10 ^ 24);
(* Planck 2015, arXiv: 1502.01589 *)
msol = 2 * 10 ^ 33;
kpc = 3.086 * 10 ^ (21);
G = 6.67 * 10 ^ (-8);

(* parameter for the tidal case *)
Dist = 100 * kpc;
(* distance between host and test sphere *)
Mvirt = 10 ^ (13);
(* virial mass of the host galaxy *)

(* parameter for the isolated DM sub-halo case *)
Mvird = 10 ^ (9);
(* virial mass of the DM sub-halo *)
alpha = 1.49809;
beta = -0.02499;
gamma = 0.0056;
 (* concentration parameter of the DM sub-halo *)
cd =
  10 ^
   (alpha + beta * Log10[Mvird] *
      (1 + gamma * (Log10[Mvird]) ^ 2));
```



```
(* cd from Correa et al. 2015 *)

(* characteristic densities for the host and
  the DM sub-halo *)
rho0t = rhoc * deltac[ct];
rho0d = rhoc * deltac[cd];

(* scale radii for the host and the DM sub-halo *)
r0t =
  (Mvirt *
     msol /
      (4 * Pi * rho0t * (Log[1 + ct] - ct / (1 + ct)))) ^
   (1 / 3);
r0d =
  (Mvird *
     msol /
      (4 * Pi * rho0d * (Log[1 + cd] - cd / (1 + cd)))) ^
   (1 / 3);

(* For a given distance to the host galaxy Dist,
this plot shows on the
  y-axis the ratio between the tidal field
  acceleration ay and the acceleration ar
  inside a DM subhalo with mass Mvird,
characteristic density rho0d, and scale
  radius r0d. The value on the x-
 axis shows the radius r of the test sphere
  in cm. *)
Plot[ay[r] / ar[r], {r, 1 * kpc, 50 * kpc}]
```

Ploeckinger (subm.)

Get the survival of TDGs in 5 easy steps

1. Take your favourite TDG

2. Estimate / Measure the distance to the center of the host halo

3. Estimate / Measure the mass of the host halo

4. Find out which DM halo mass has equivalent accelerations than the tidal field.

5. Would a DM dwarf galaxy survive in this DM halo?

Summary

High-resolution chemo-dynamical simulations are necessary but costly.

Only very limited parameter space can be explored (orbit, masses, numerical methods…)

The survival of isolated DGs (in the LCDM framework DM dominated) is undoubted.

I propose a quick and easy method that can be used as a proxy for the survival probability of TDGs.