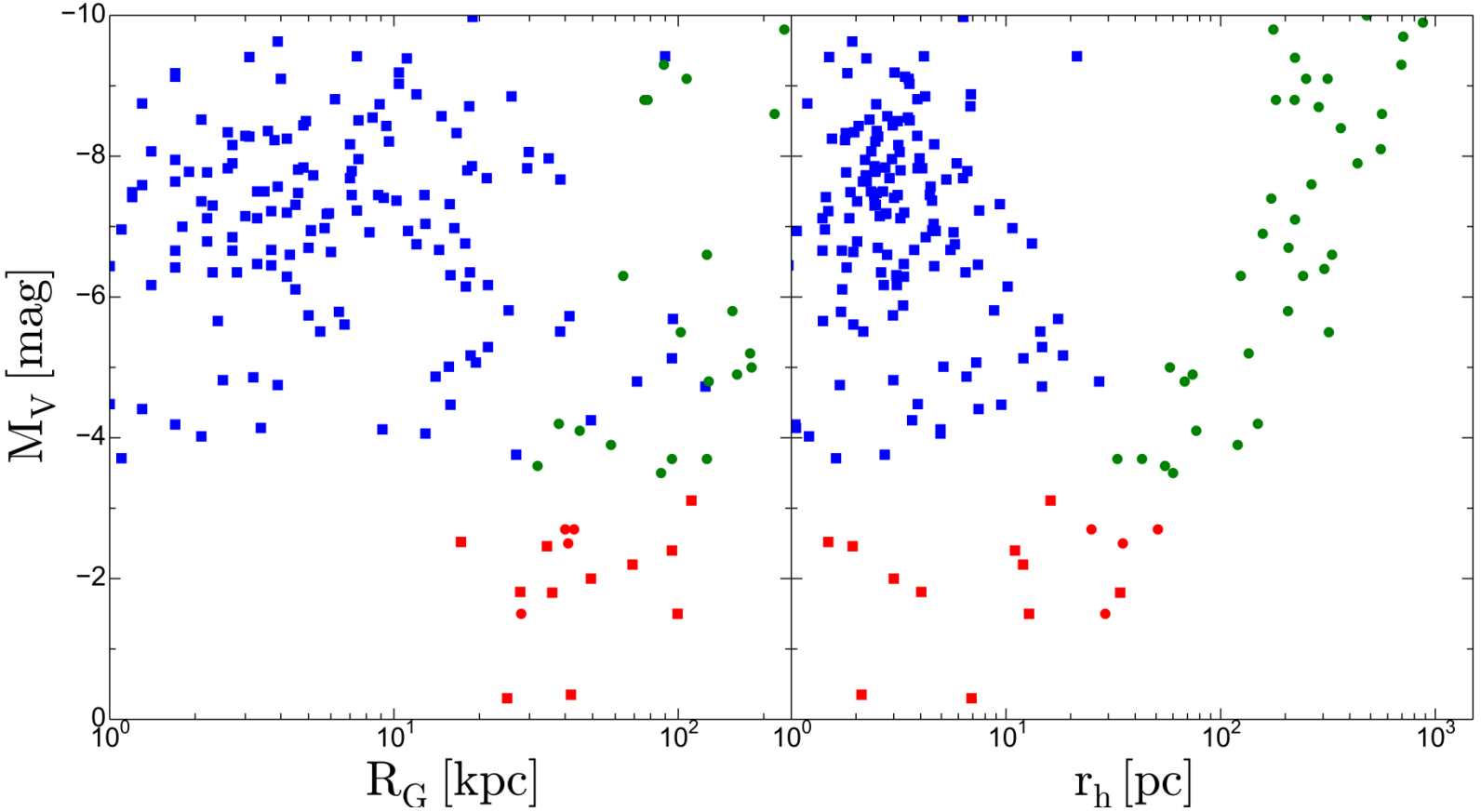
Filippo Contenta

Collaborators:
Mark Gieles
Eduardo Balbinot

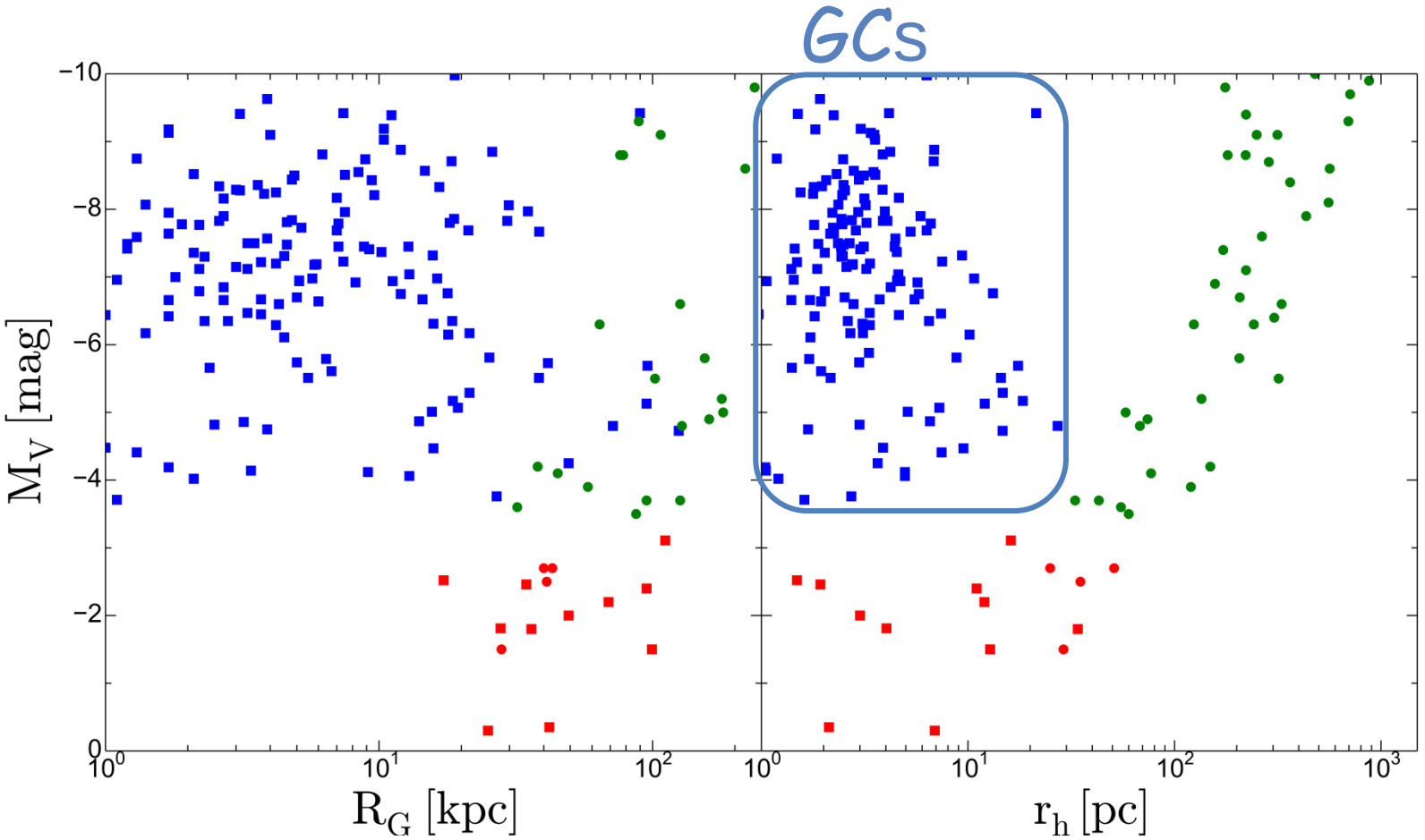
Faint Stellar Systems in the outer halo of the Milky Way

The Milky Way Satellites



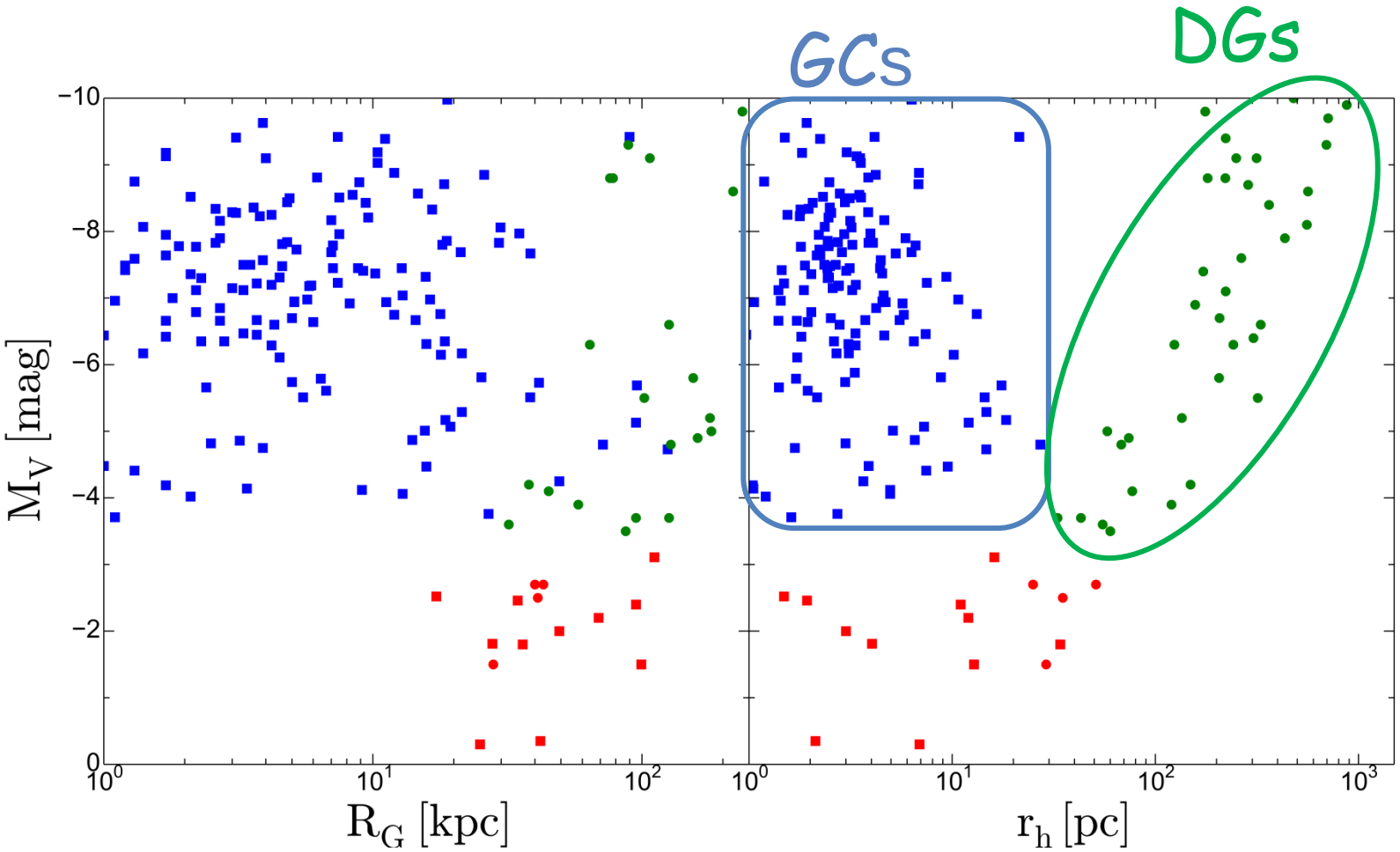
Harris (2010) , McConnachie (2012) ,
Bechtol et al. (2015) , Belokurov et al. (2015)

The Milky Way Satellites



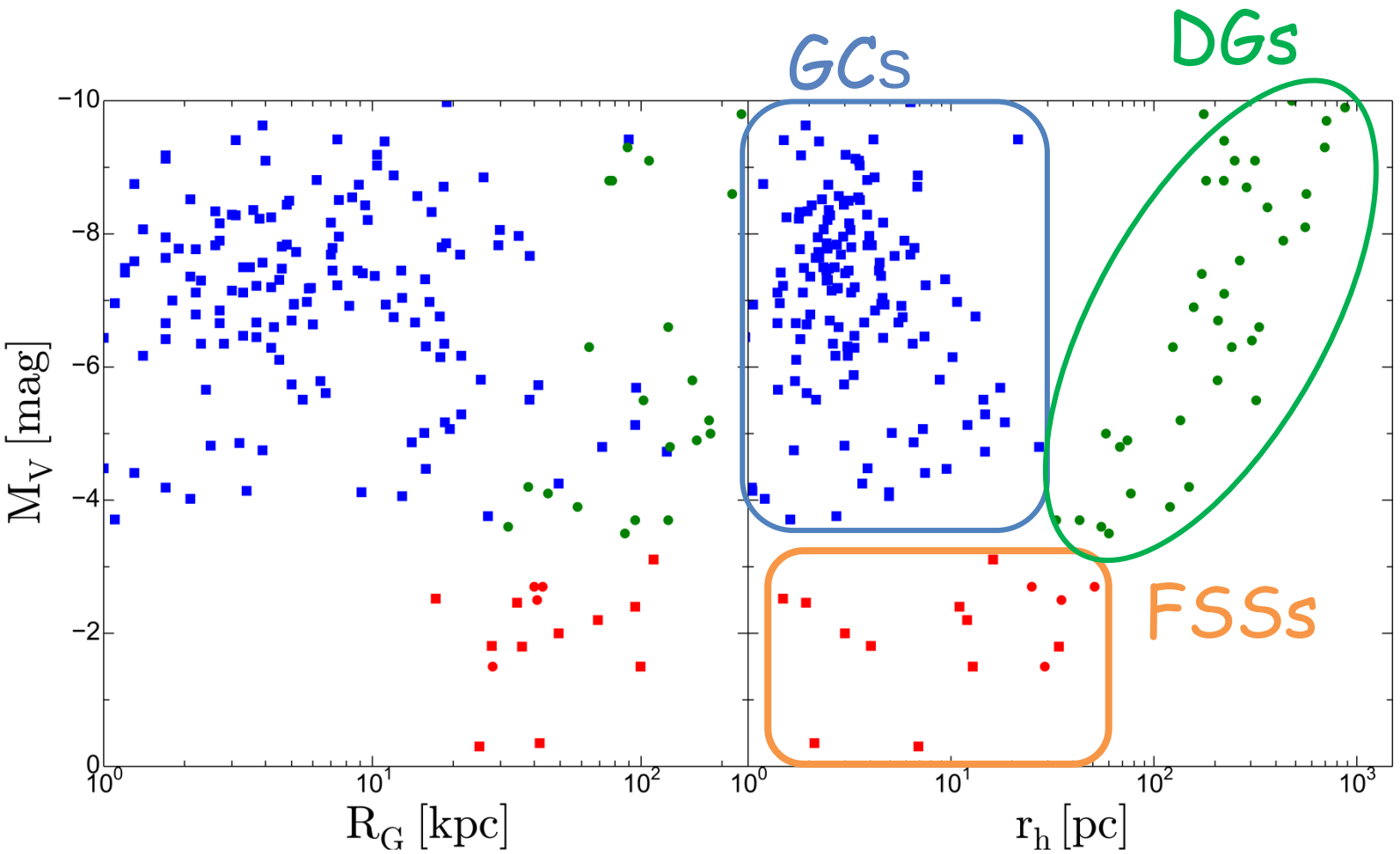
Harris (2010) , McConnachie (2012) ,
Bechtol et al. (2015) , Belokurov et al. (2015)

The Milky Way Satellites



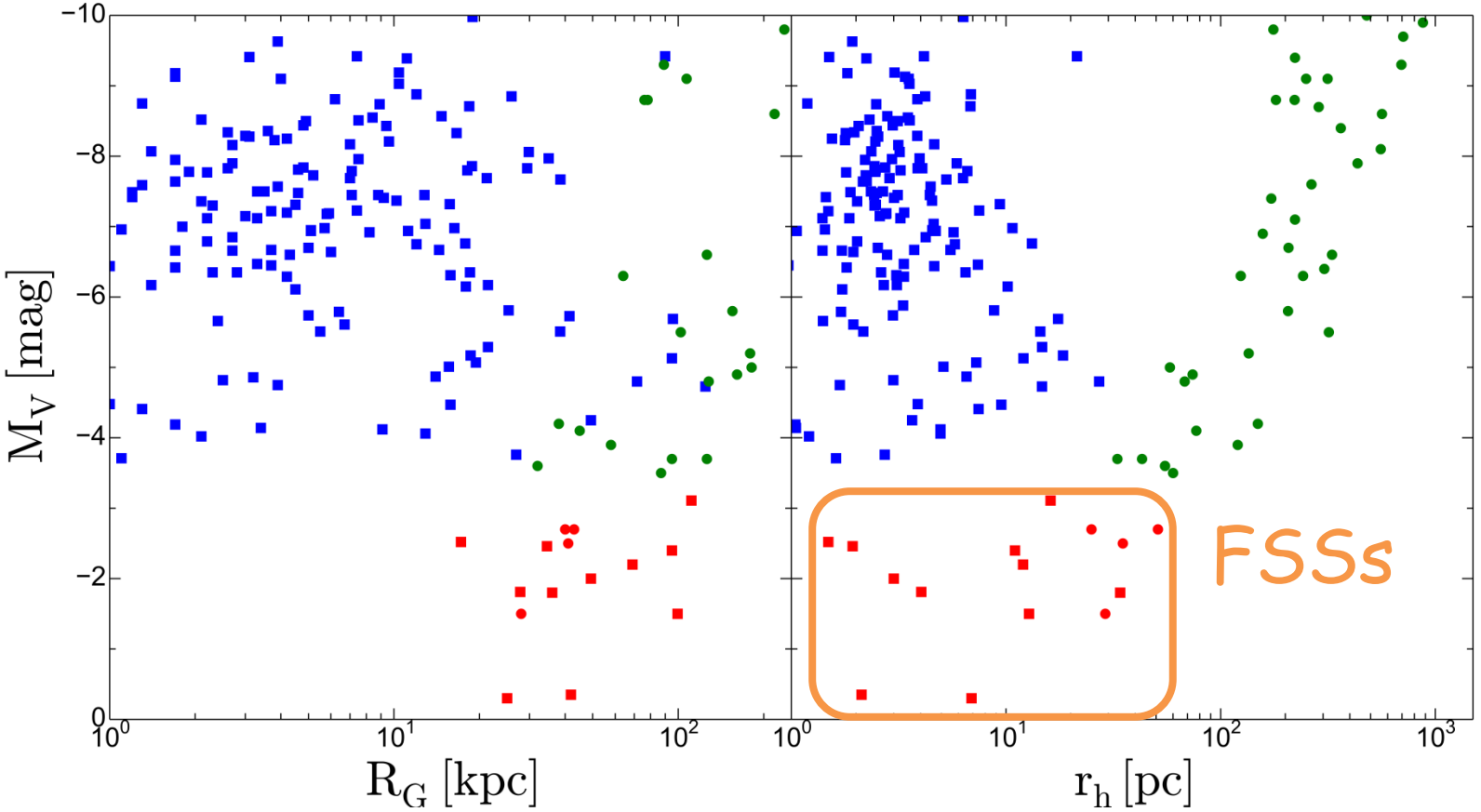
Harris (2010) , McConnachie (2012) ,
Bechtol et al. (2015) , Belokurov et al. (2015)

The Milky Way Satellites



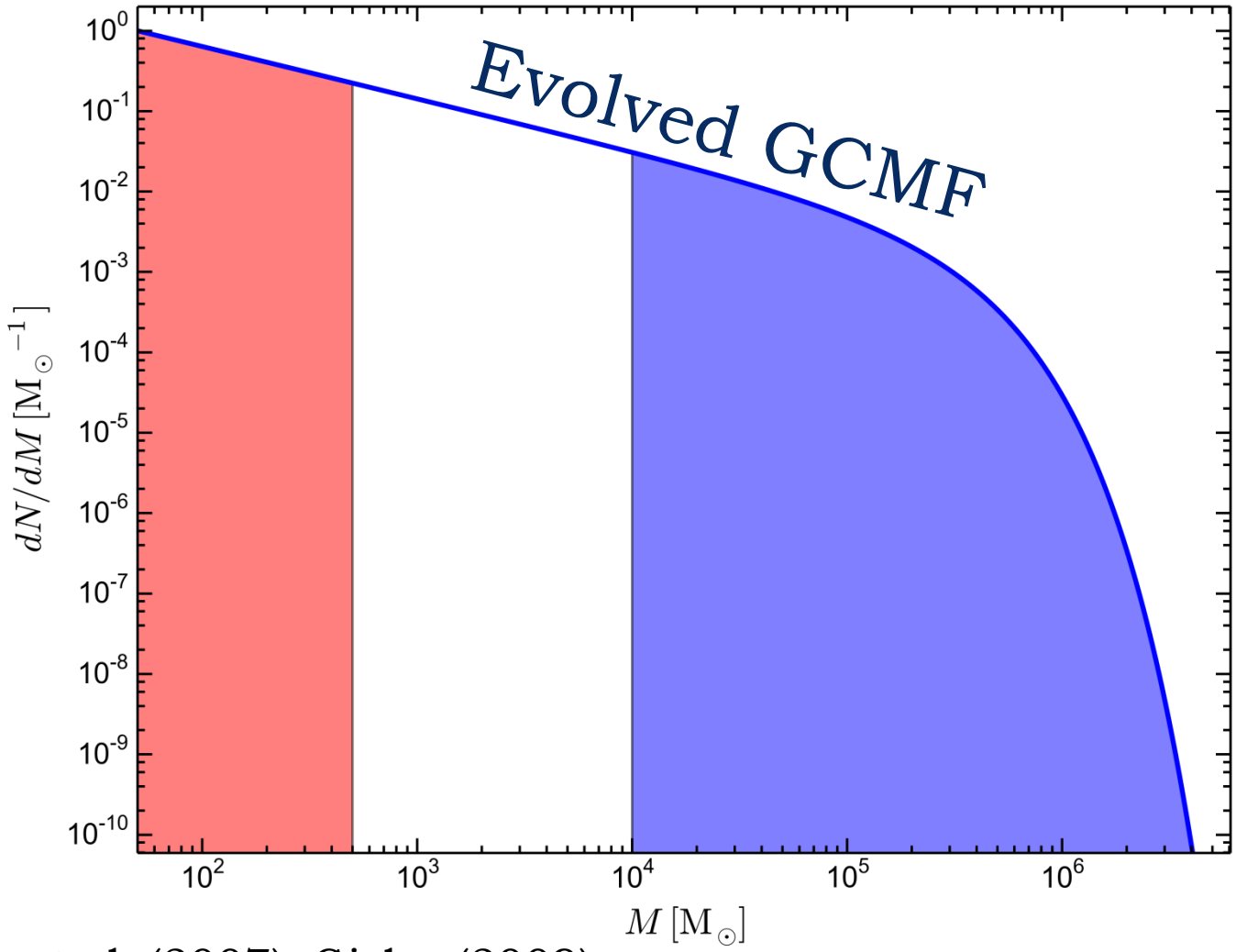
Harris (2010) , McConnachie (2012) ,
Bechtol et al. (2015) , Belokurov et al. (2015)

The Milky Way Satellites



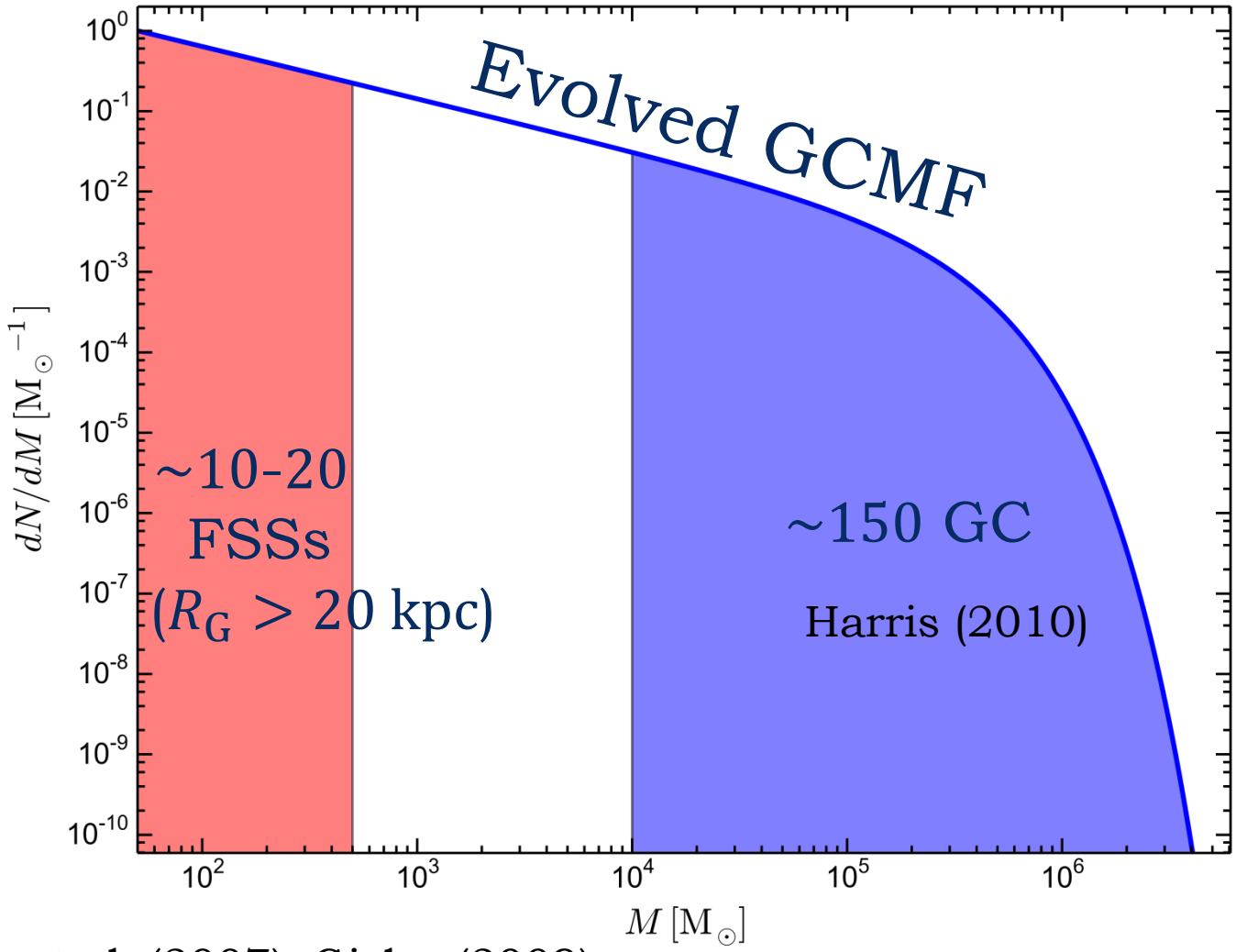
Harris (2010) , McConnachie (2012) ,
Bechtol et al. (2015) , Belokurov et al. (2015)

Estimate of the number of star clusters



Jordán et al. (2007), Gieles (2009)

Estimate of the number of star clusters



Jordán et al. (2007), Gieles (2009)

The Milky Way Satellites

Wil 1 Willman et al. (2005)

metallicity spread

$\sigma \sim 0$ km s^{-1}

Belokurov et al. (2007)

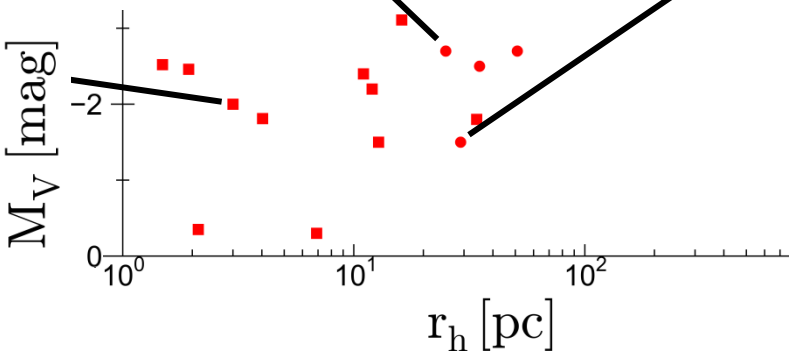
Segue

metallicity spread

$\sigma \sim 3.7$ km s^{-1}

Ko 1

Koposov et al. (2007)



Star clusters

$$\frac{r_{\rm h}}{r_{\rm J}} \sim 0.15$$ Hénon (1961)

$$r_{\rm J} = \left(\frac{GM}{2\Omega^2}\right)^{1/3}$$

$M \sim 300\ \mathrm{M}_\odot$, $V_{\rm G} = 200\ \mathrm{km\ s^{-1}}$, $R_{\rm G} = 40\ \mathrm{kpc}$

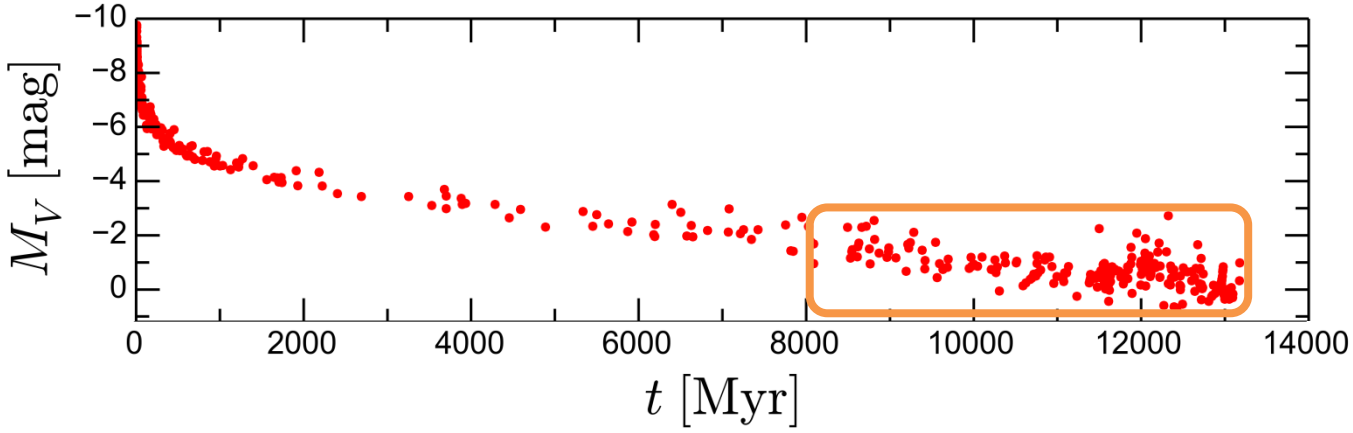
$r_{\rm J} \sim 30\ \mathrm{pc} \Longrightarrow\ r_{\rm h} \sim 4\ \mathrm{pc}$

Can star clusters contribute
to the extended FSSs population?

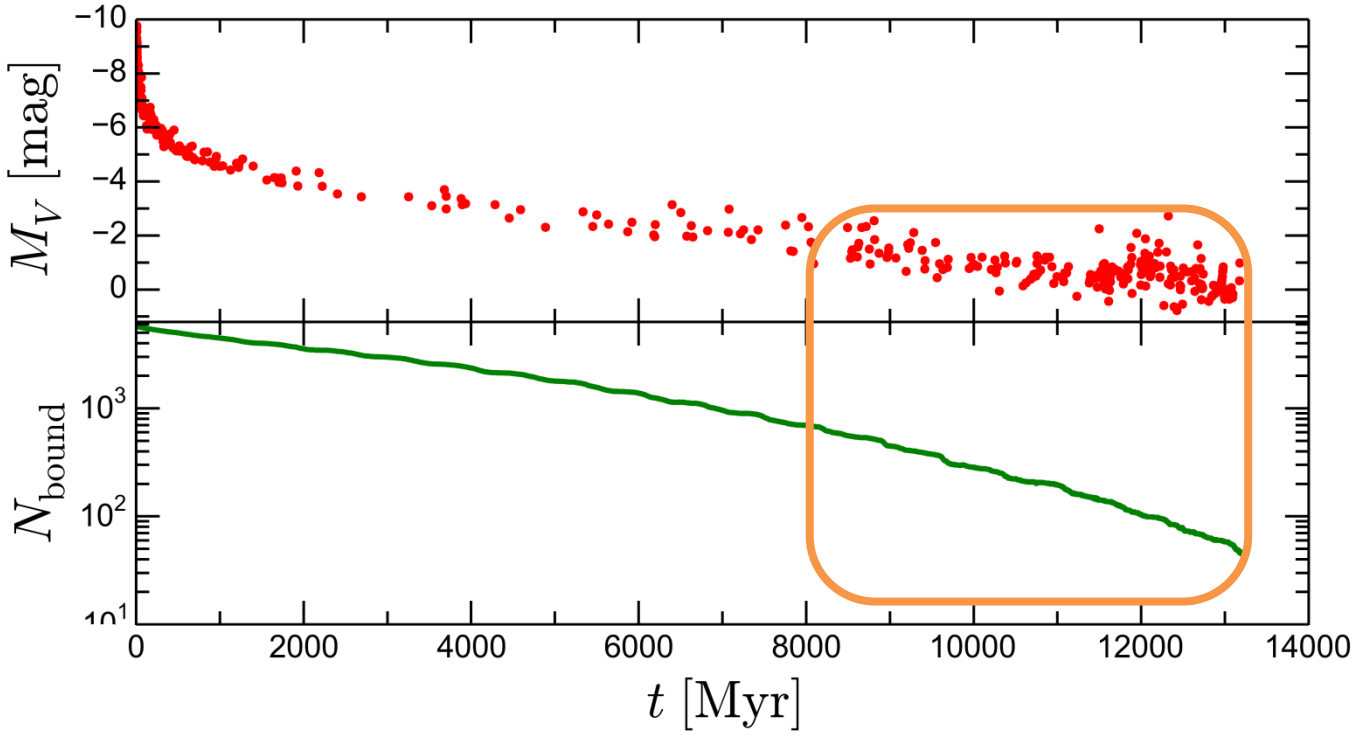
N-BODY SIMULATIONS

- NBODY6tt (Renaud & Gieles, 2015) (Nitadori & Aarseth, 2012) - Collisional code
- $1000 \lesssim N \lesssim 20000$ ($N_{12\,\mathrm{Gyr}} \sim 200$ stars)
- Plummer model (Plummer, 1911)
- $0.1 < \frac{M}{\mathrm{M}_\odot} < 100$, Kroupa IMF (Kroupa, 2001)
- Roche filling $\left(\frac{r_\mathrm{h}}{r_\mathrm{J}} = 0.1\right)$, underfilling $\left(\rho_\mathrm{h} = 10^4 \frac{\mathrm{M}_\odot}{\mathrm{pc}^3}\right)$
- $R_\mathrm{apo} = (50,\ 100,\ 150)$ kpc , $e = (0,\ 0.25,\ 0.5,\ 0.75)$
- NFW potential $\phi_\mathrm{NFW} = -\frac{GM}{R_\mathrm{G}} \ln\left(1 + \frac{R_\mathrm{G}}{R_0}\right)$ (NFW, 1996)

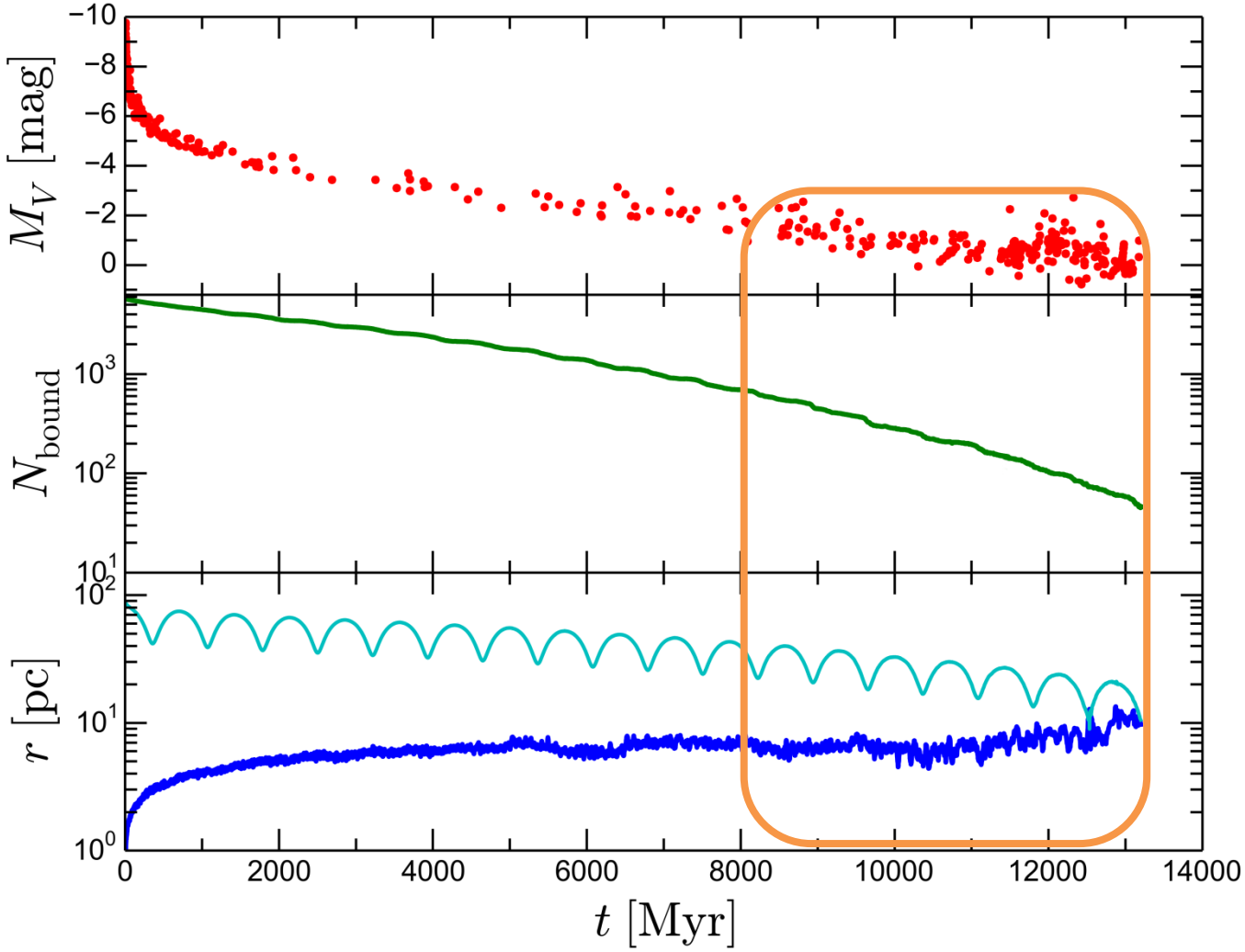
Example $R_{\mathrm{APO}} = 50$ kpc, $e = 0.5$, $N = 6000$



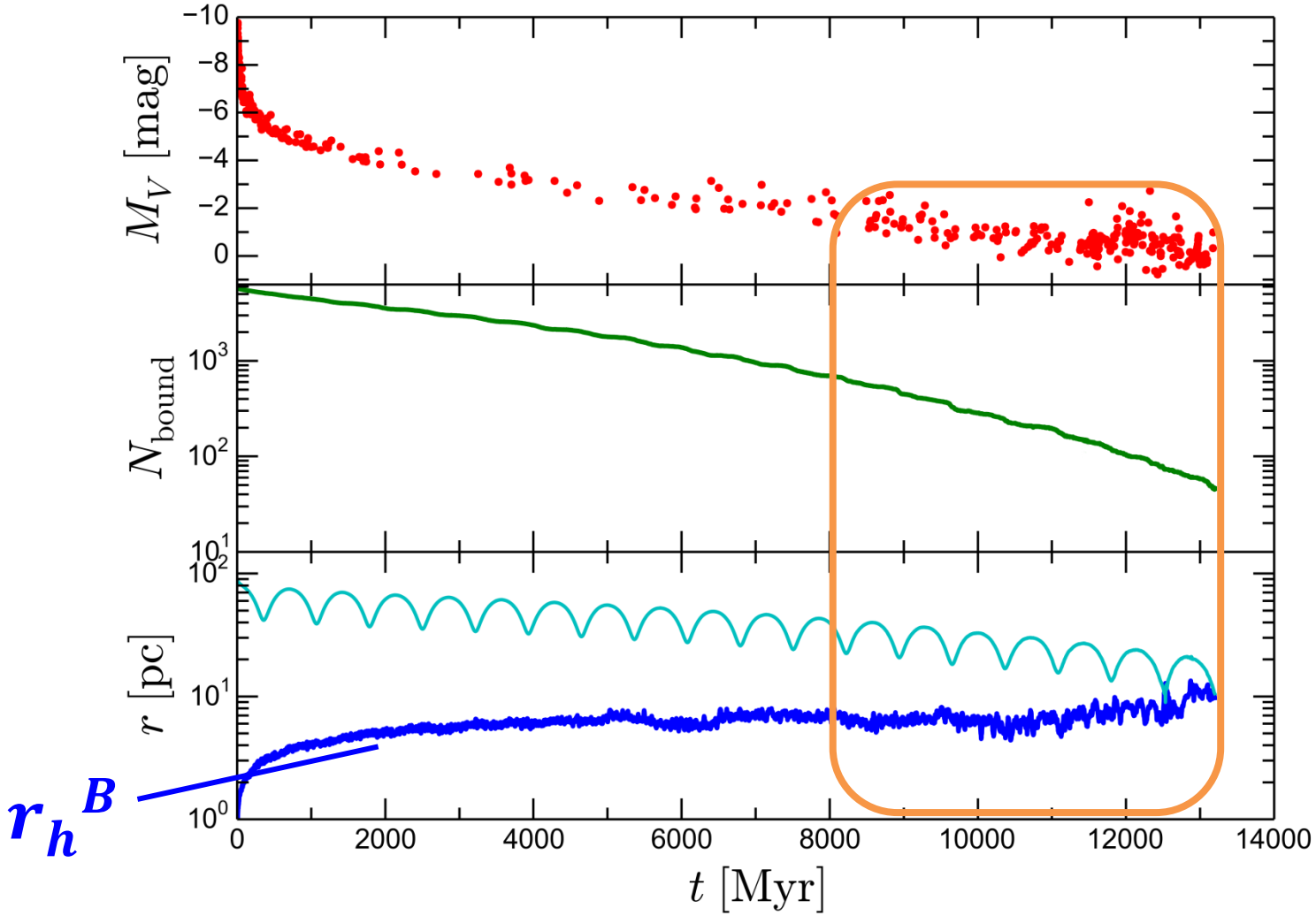
EXAMPLE $R_{\mathrm{APO}} = 50$ kpc, $e = 0.5$, $N = 6000$



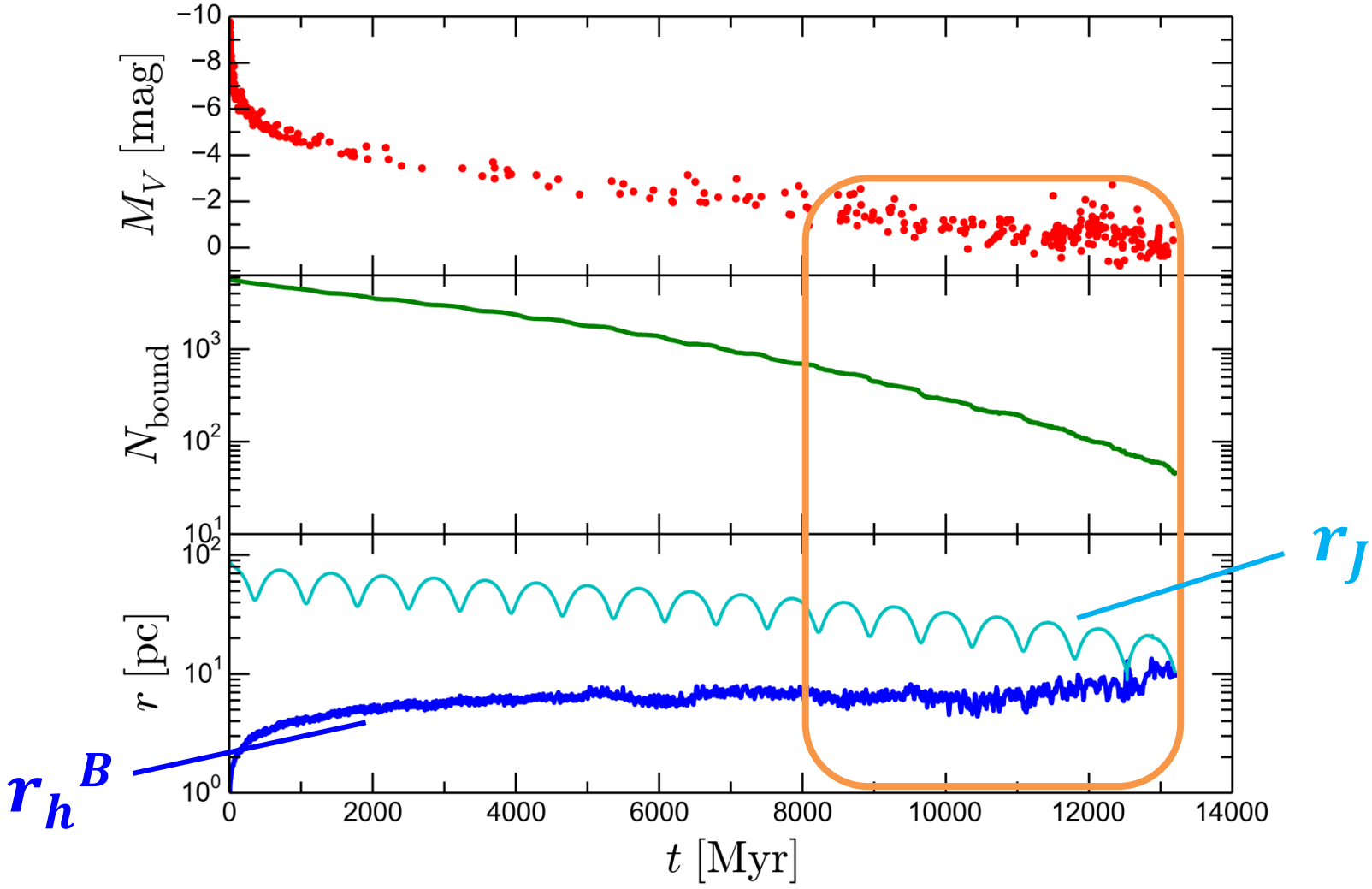
EXAMPLE $R_{\mathrm{APO}} = 50$ kpc, $e = 0.5$, $N = 6000$



EXAMPLE $R_{\rm APO} = 50$ kpc, $e = 0.5$, $N = 6000$



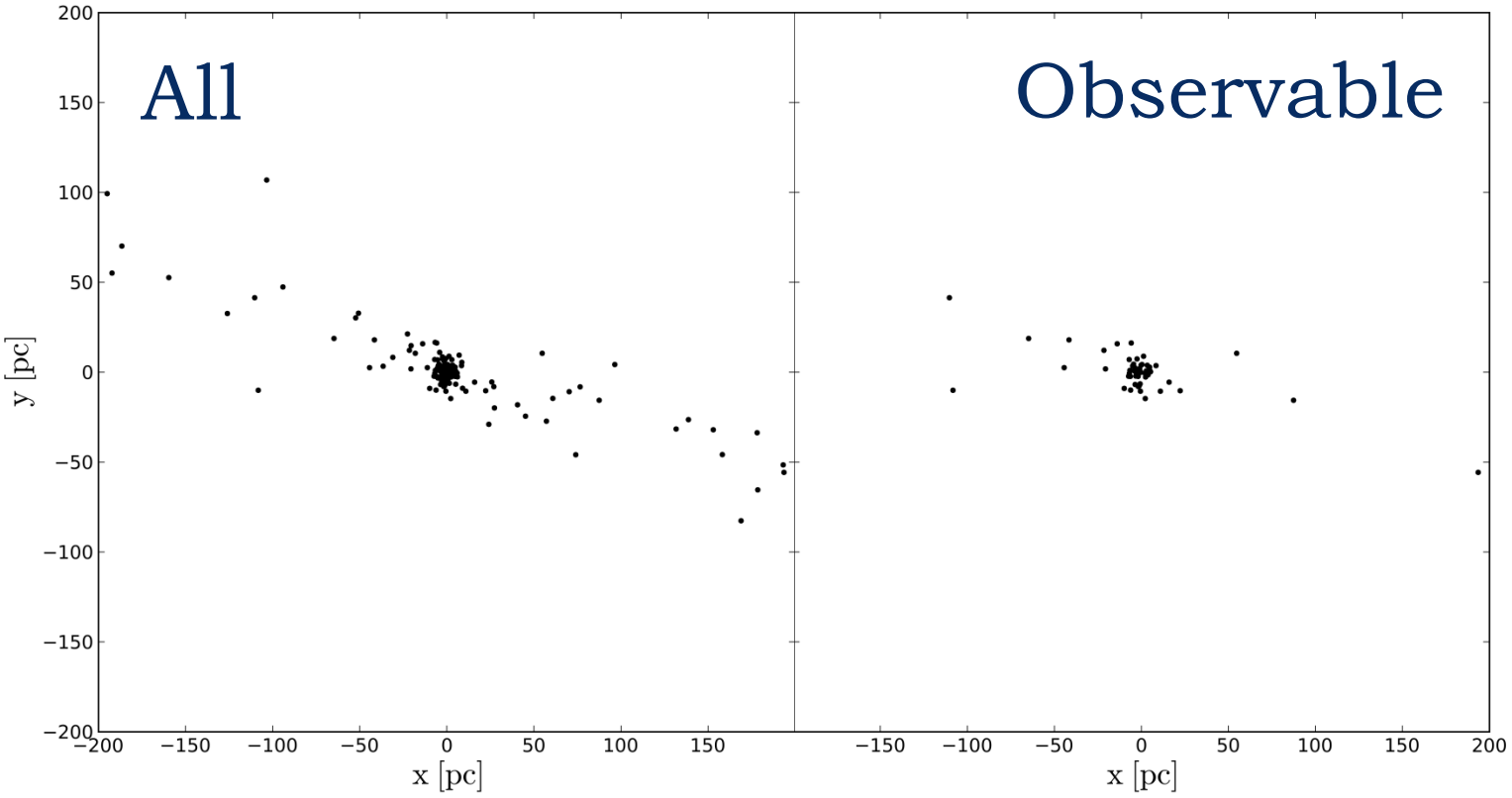
EXAMPLE $R_{\mathrm{APO}} = 50$ kpc, $e = 0.5$, $N = 6000$



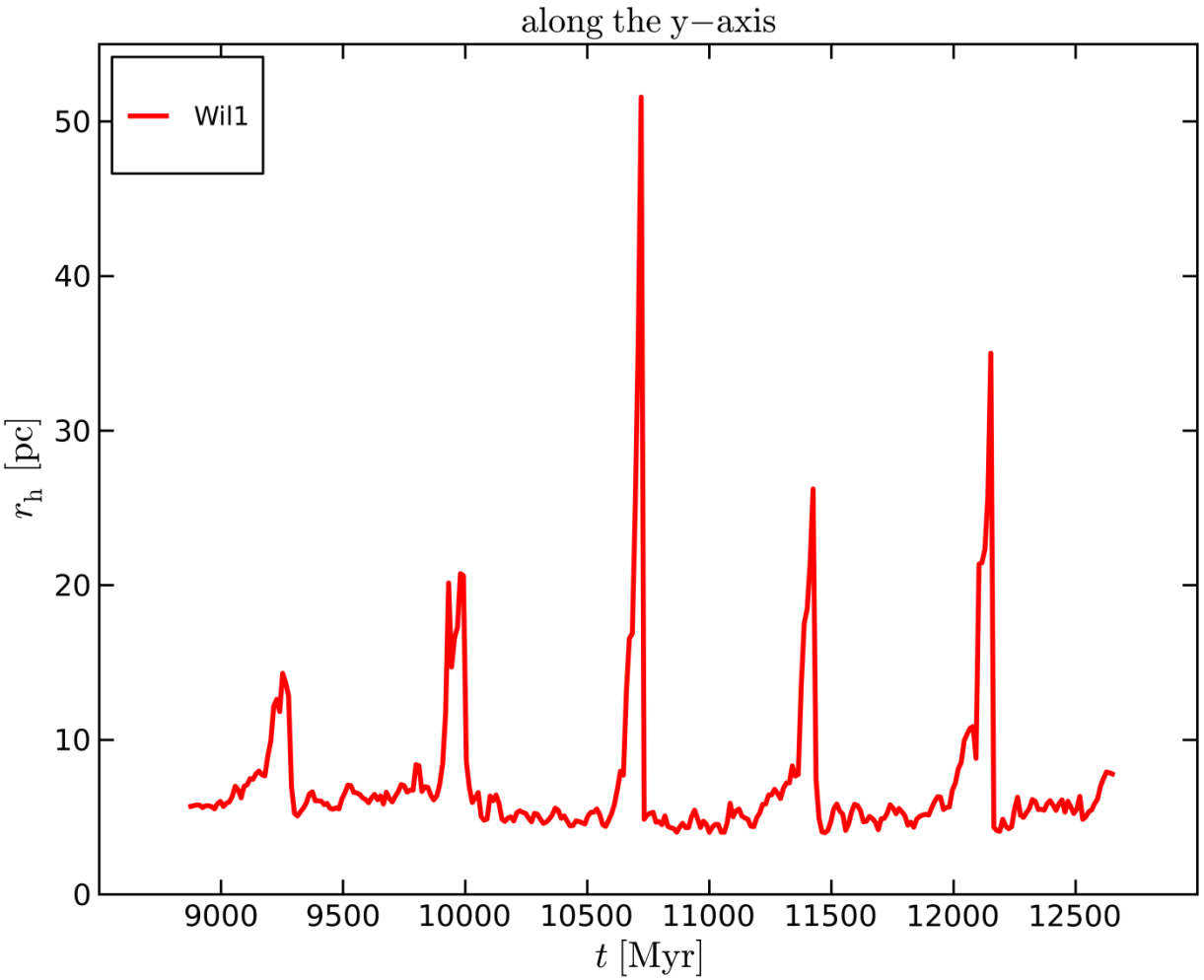
Analysis in the observational space

- Consider only luminous stars (no remnants and $m > 0.5\ M_{\odot}$) bound & unbound
- Study different points in the orbit (e.g. apo, peri)
- Add background stars (based on Galactic model, TRILEGAL 1.6) (Girardi et al., 2012)
- Maximum Likelihood fit on number density profile (Martin et al., 2008)
- Consider different lines of sight

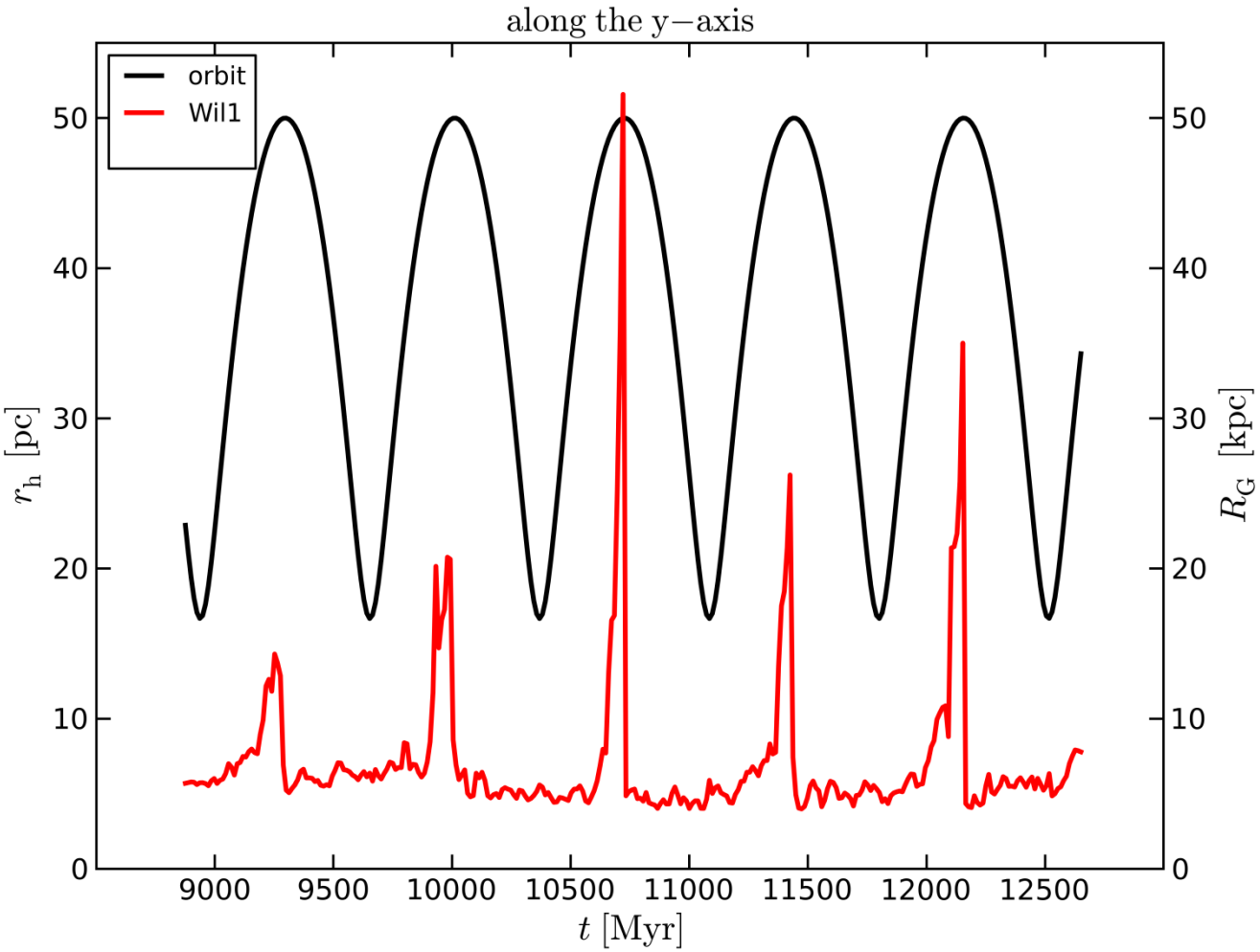
Luminous stars (bound & unbound)



Evolution of the size

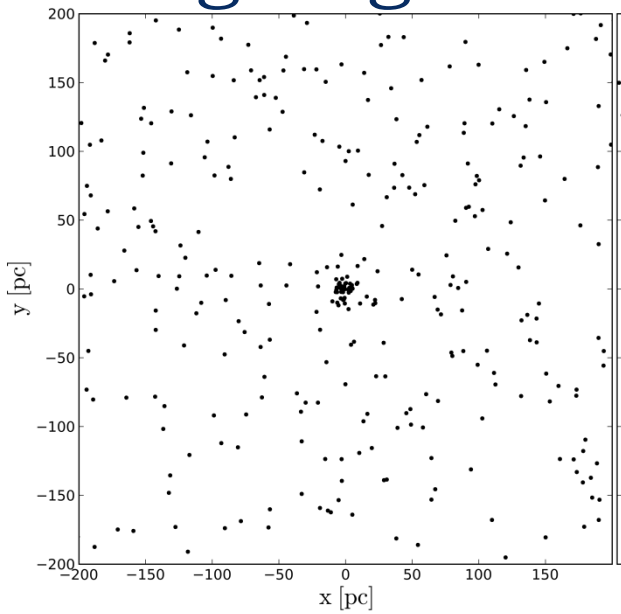


Evolution of the size

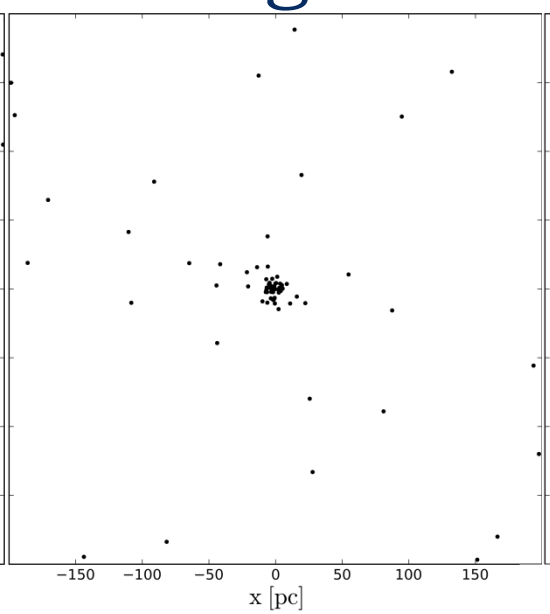


Background Stars

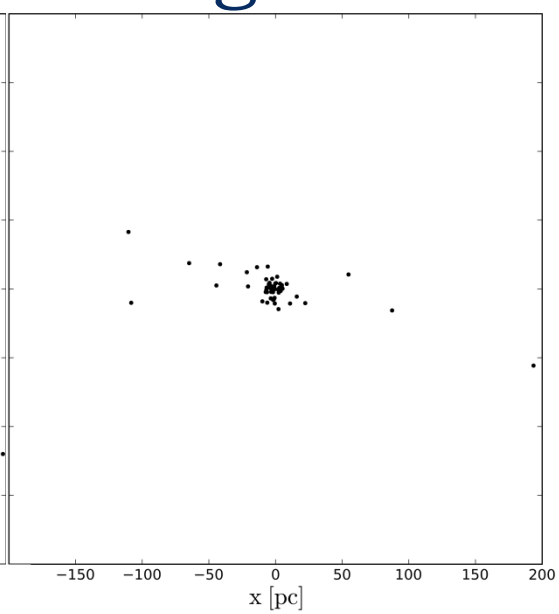
High bg



Low bg



No bg



WHY?

Willman et al. (2005)

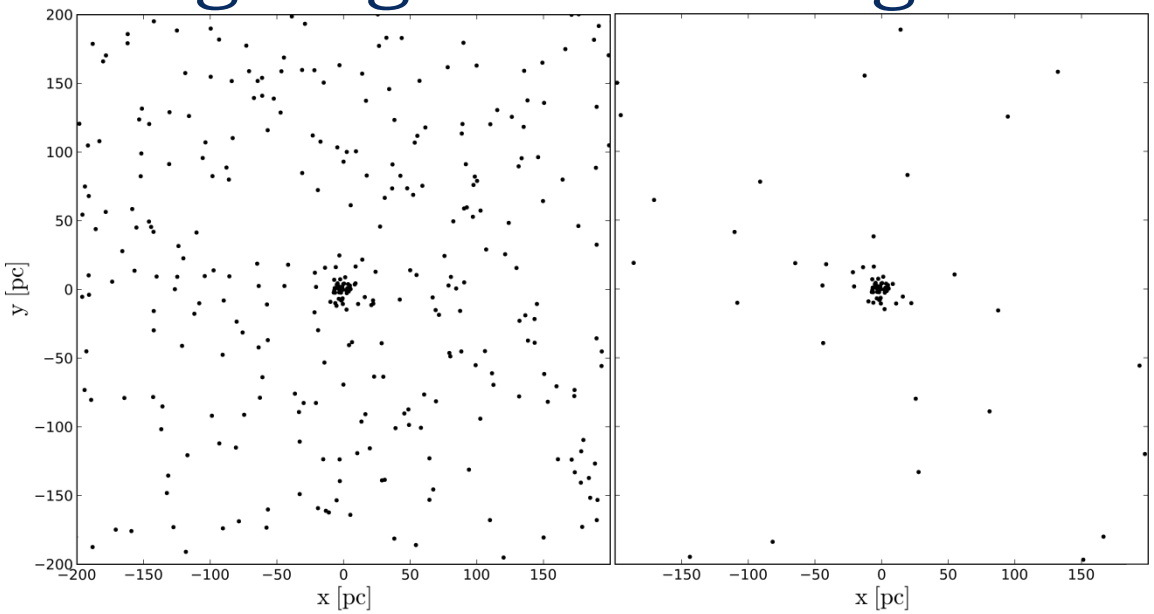
Wil 1 r_h~25 pc

Ko 1 r_h~3 pc

Koposov et al. (2007)

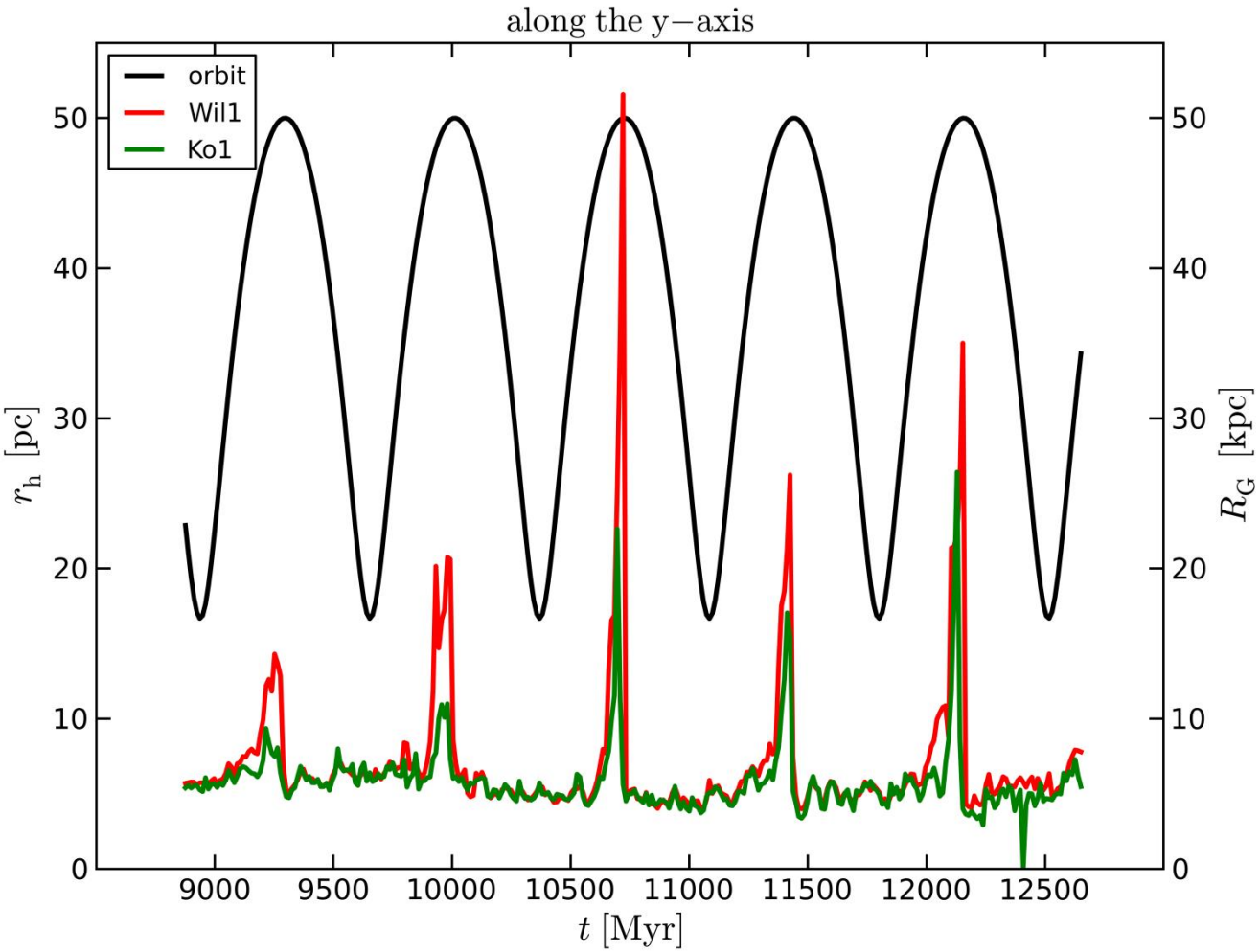
High bg

Low bg



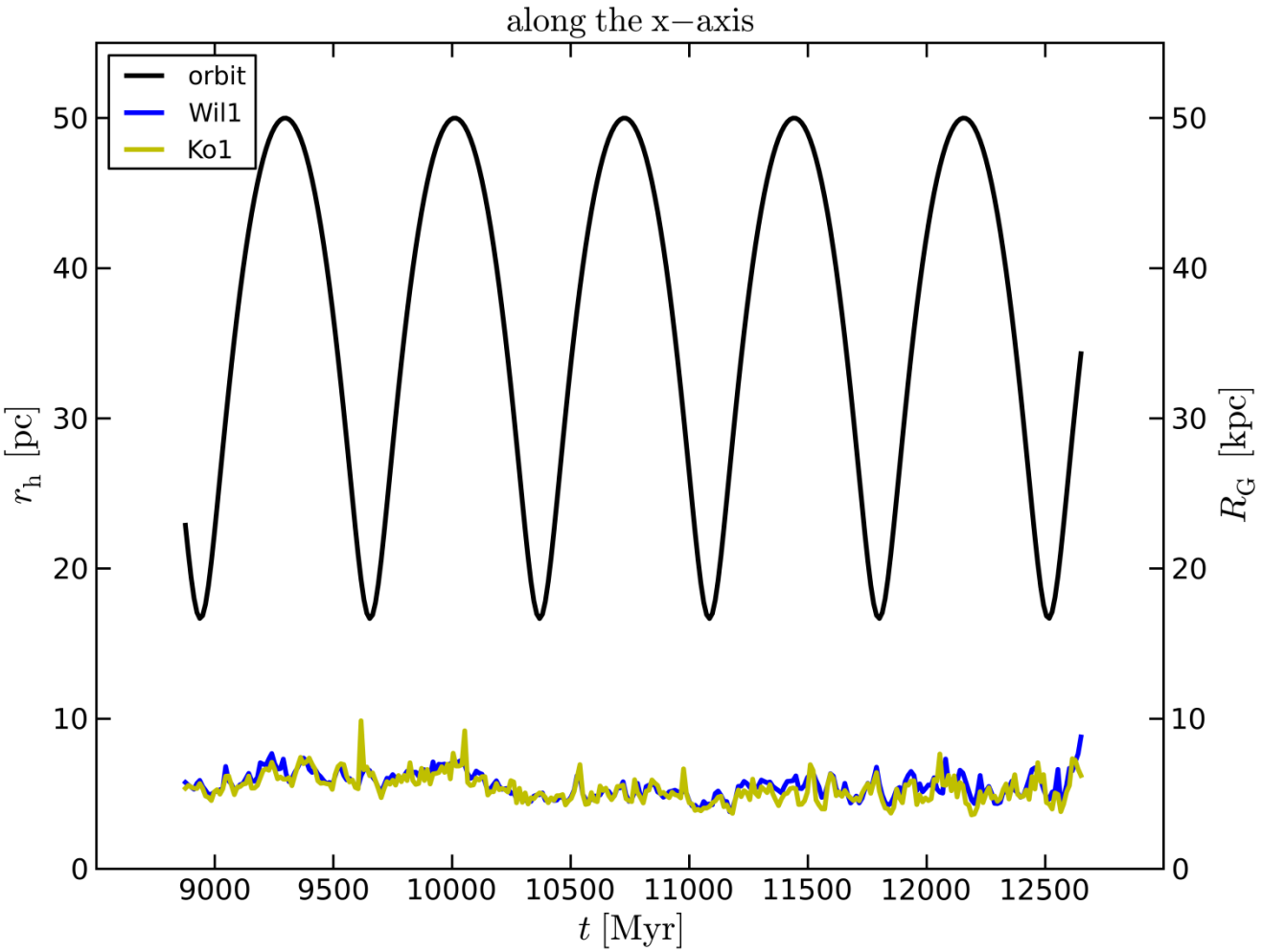
Can the background stars influence the observed r_h?

Evolution of the size

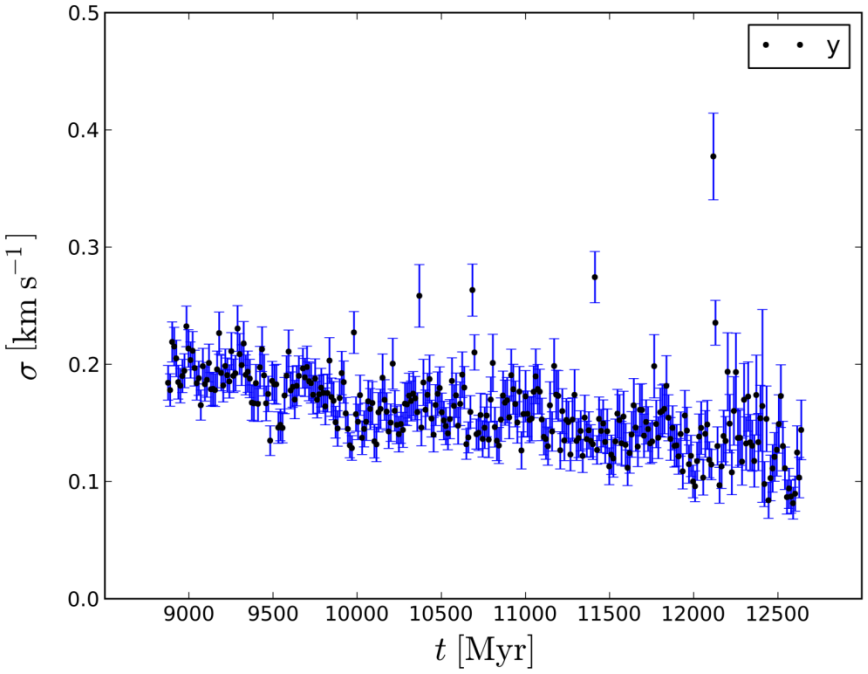


Different LOS

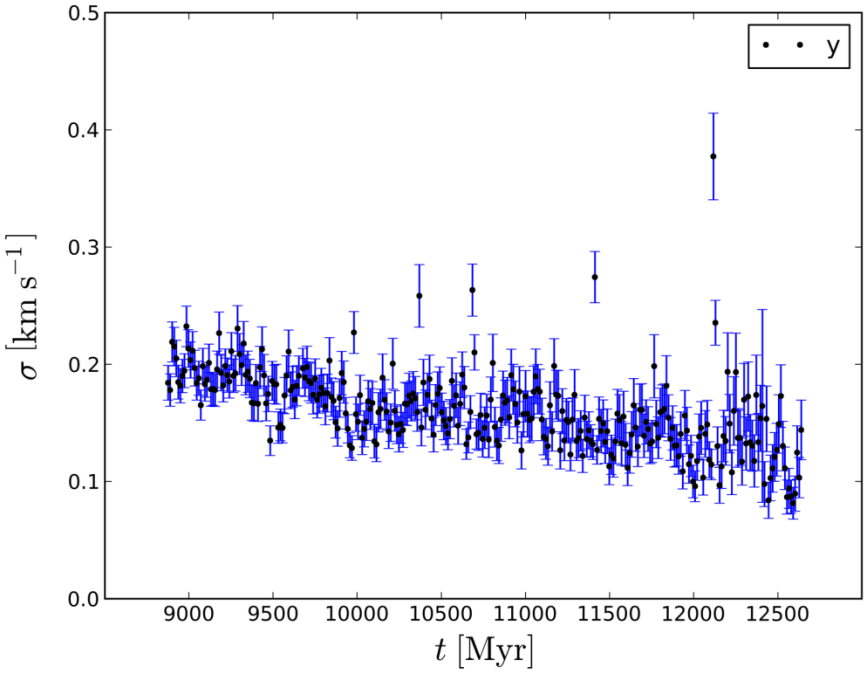
Evolution of the size

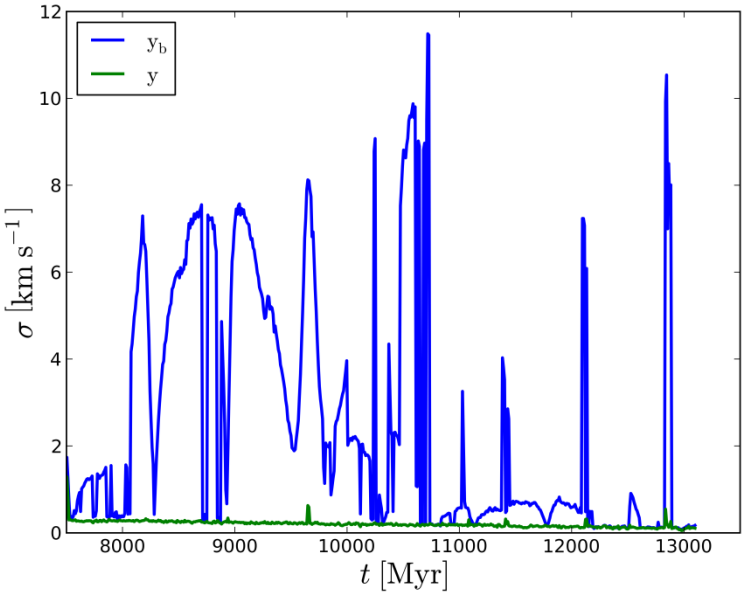


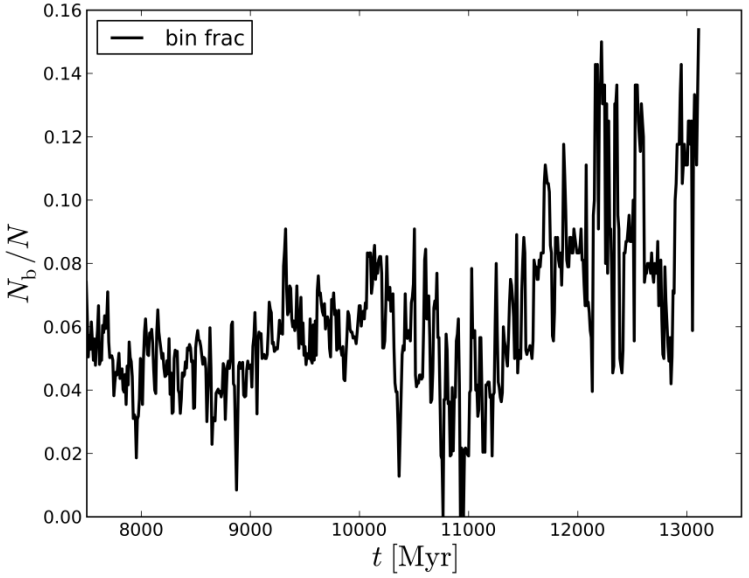
Kinematics within r_h



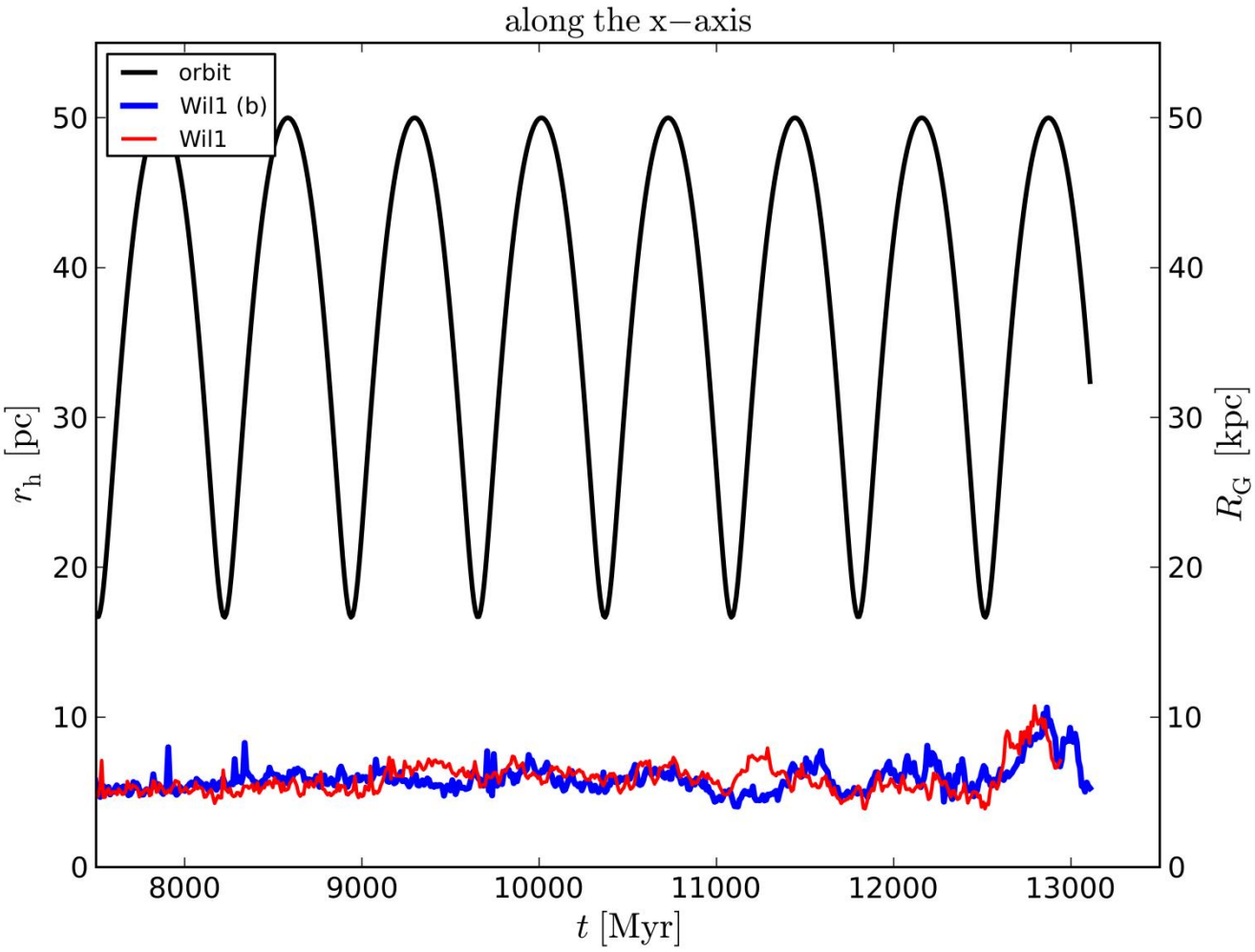
Kinematics within r_h – with binaries





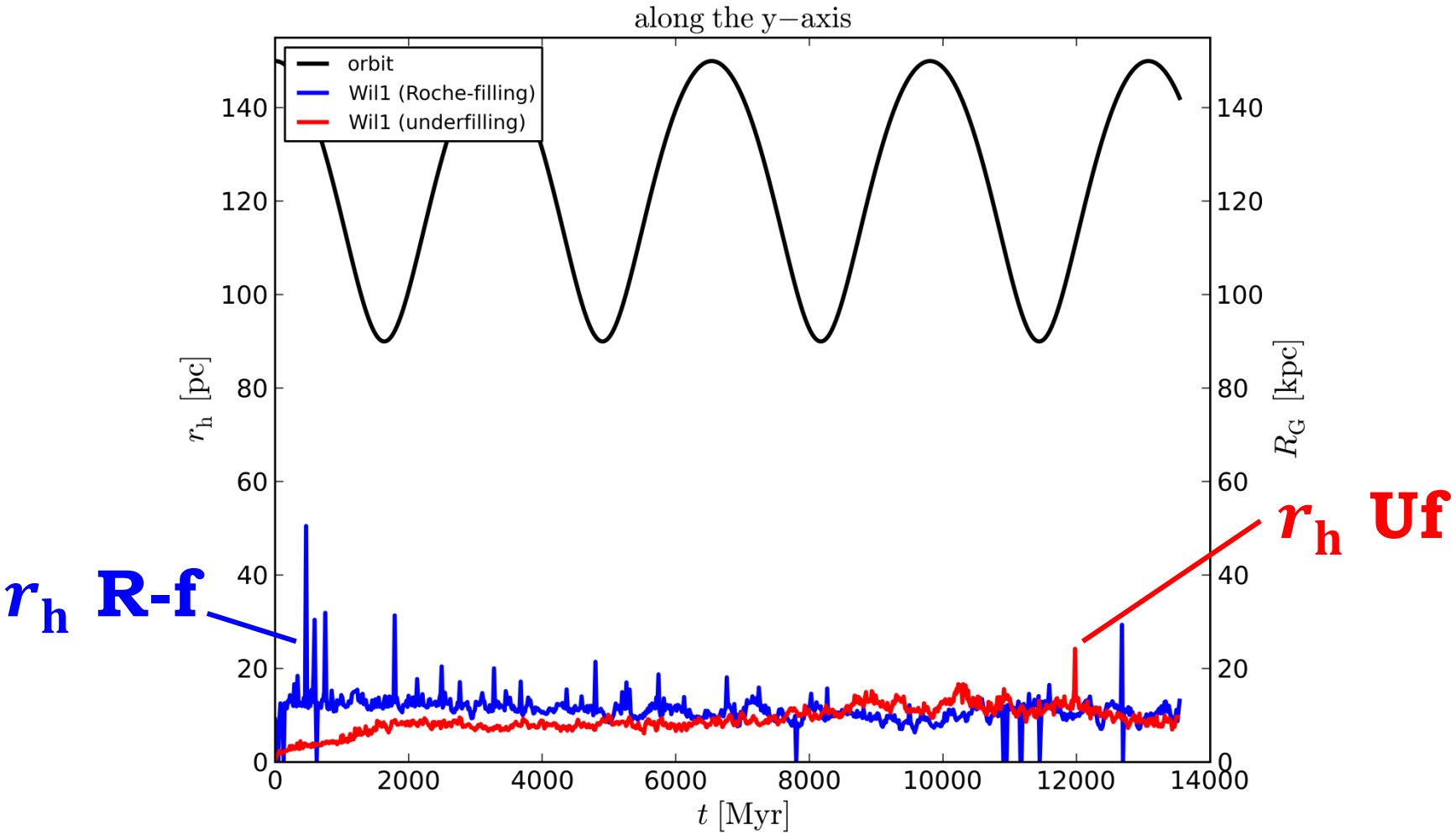


Binaries - Evolution of the size



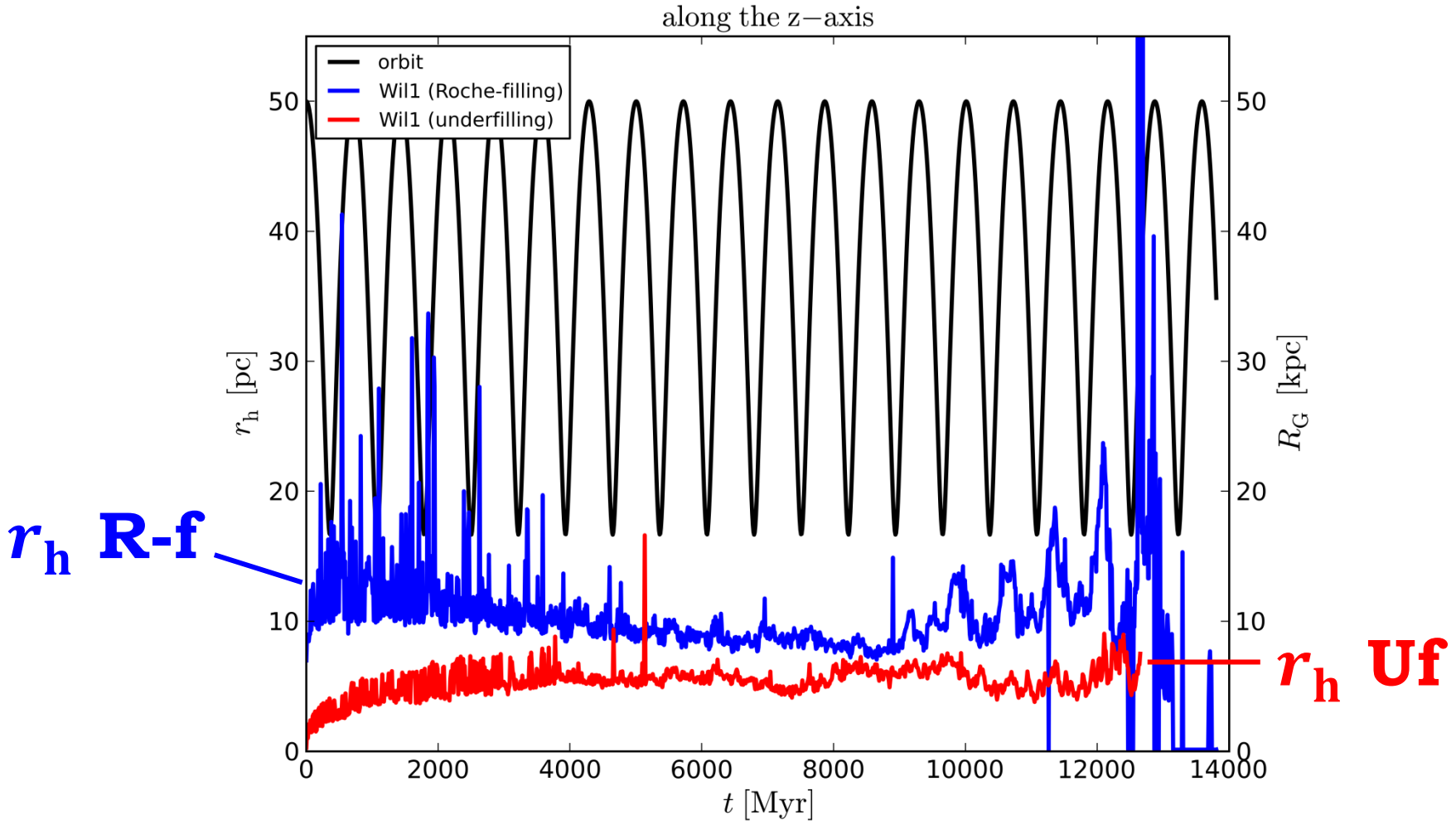
Roche-filling vs Underfilling

$R_{\rm APO} = 150$ kpc, $e = 0.25$



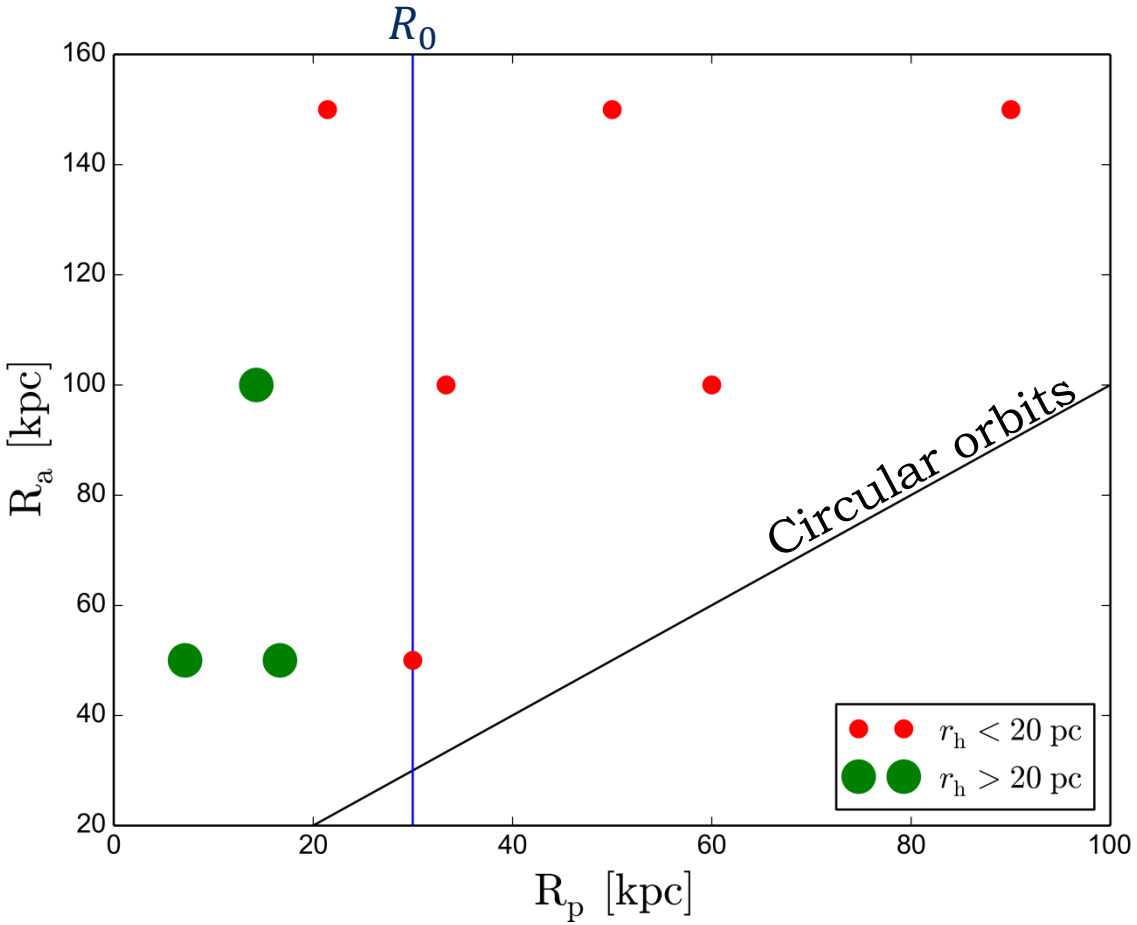
Roche-filling vs Underfilling

$R_{\rm APO} = 50$ kpc, $e = 0.5$



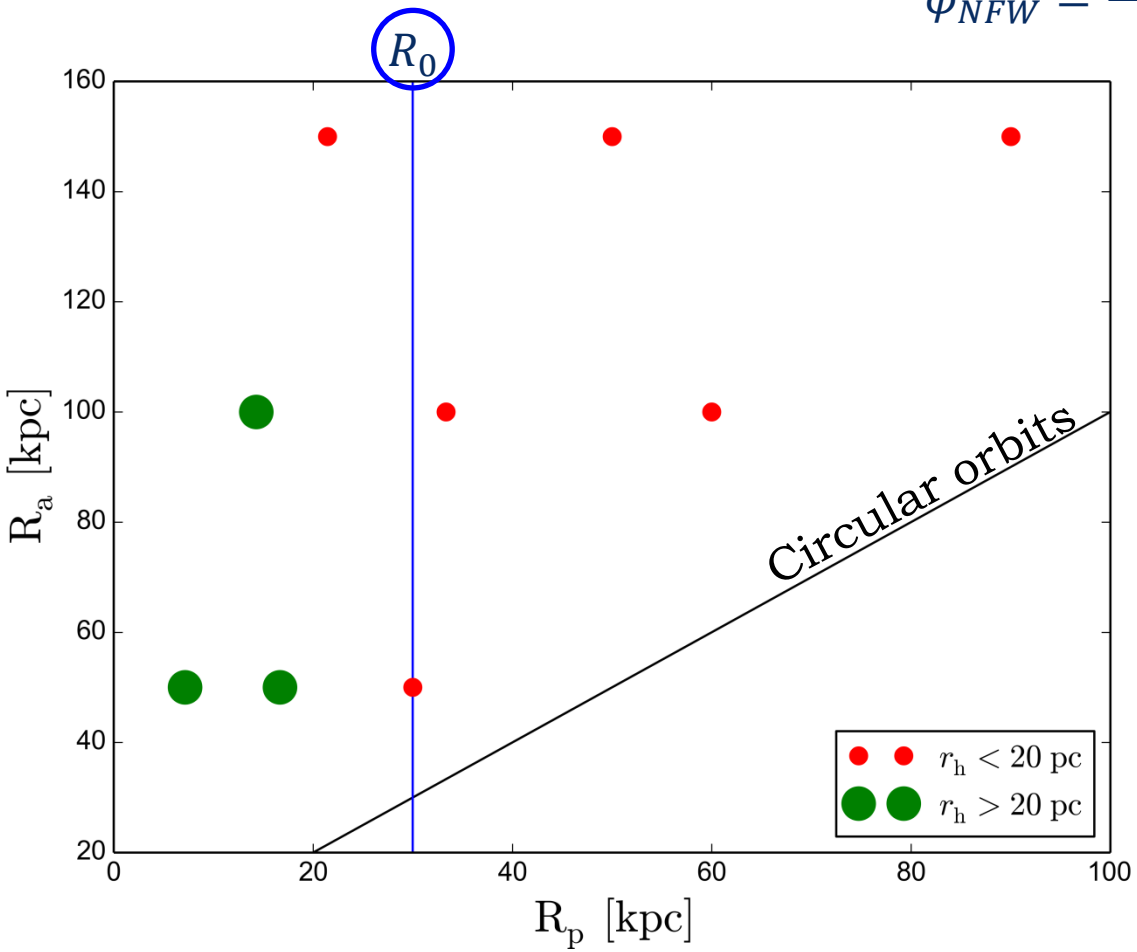
The effect of cluster orbit

$$\phi_{NFW} = -\frac{GM}{R_G}\ln\left(1+\frac{R_G}{R_0}\right)$$



The effect of cluster orbit

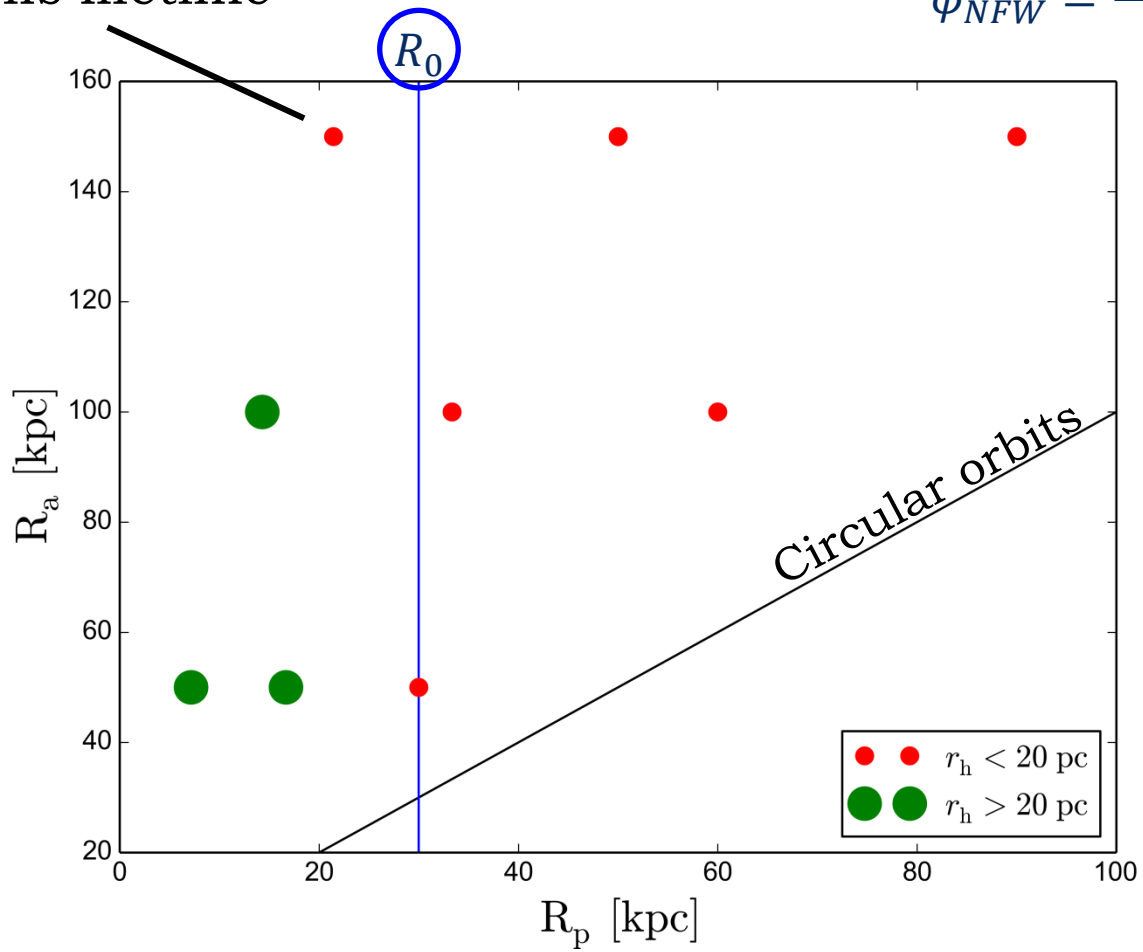
$$\phi_{NFW} = -\frac{GM}{R_G}\ln\left(1+\frac{R_G}{R_0}\right)$$



The effect of cluster orbit

~ 5% of his lifetime

$$\phi_{NFW} = -\frac{GM}{R_G}\ln\left(1+\frac{R_G}{R_0}\right)$$



Conclusion

The recipe to appear extended:

- mainly along y-axis (the least probable LOS)
- in apocentre
- easier if it was a Roche-filling cluster
- enough time spent within the scale radius of the galactic potential

It is very unlikely to observe extended star clusters!