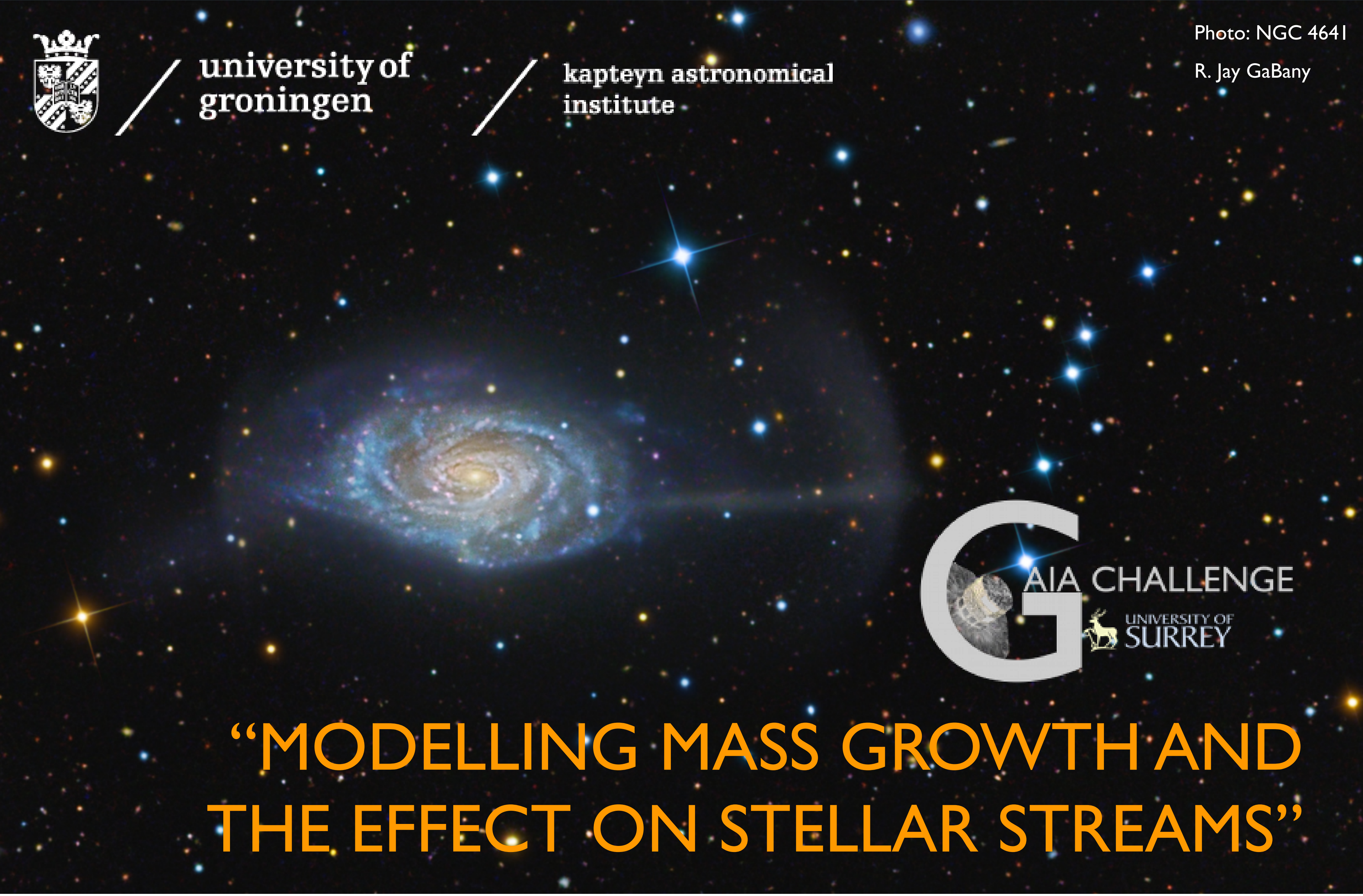

Photo: NGC 4641
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GAIA CHALLENGE
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"MODELLING MASS GROWTH AND THE EFFECT ON STELLAR STREAMS"

Hans Buist & Amina Helmi

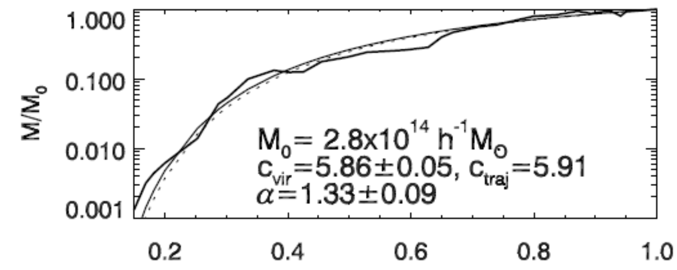
Introduction

- Tidal stripping of infalling dwarf galaxies (and globular clusters): streams
  - Stars are mostly stripped from the dwarf at pericentre
  - Stars orbit in potential of galaxy
  - Initially closeby stars spread out and form the stream, mainly due to energy differences
- Cosmology predicts galaxy mass to grow in time
  - Could have an effect on streams (Gomez & Helmi 2010, Peñarrubia 2013)
  - Need a realistic model of a time-dependent potential

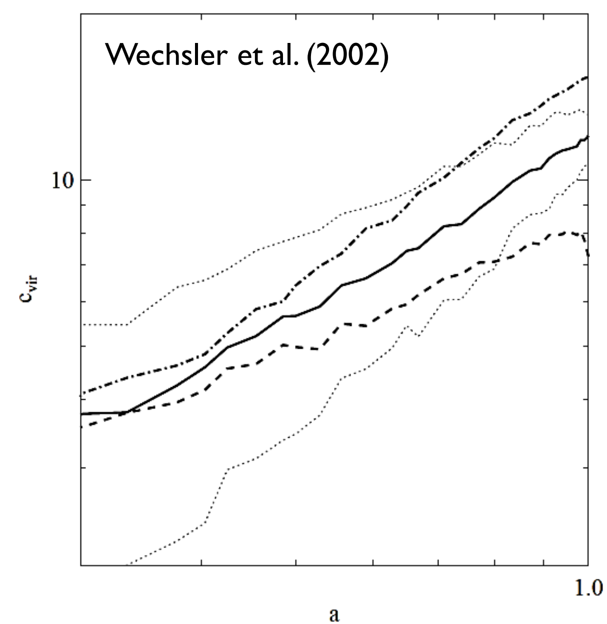
Modelling Mass Evolution in cosmological simulations: Globally

- Wechsler et al. (2002) studied characteristic parameters of dark matter halos in cosmological simulations and found

$$M_{vir}(t) = M_O \exp[-2a_c(z - z_O)]$$



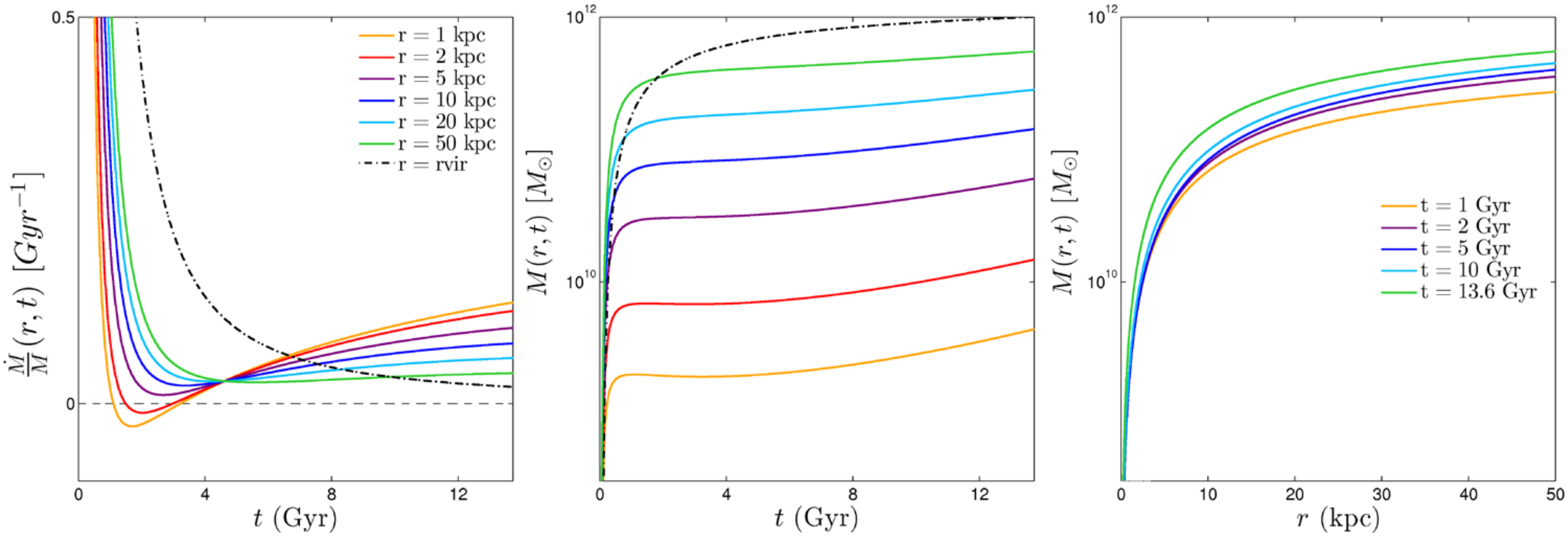
$$c_{vir}(t) \equiv \frac{r_s}{r_{vir}} = 4.1\frac{a}{a_c}$$



- Derived from *mean behaviour* of halos
- Individual halo well represented?

Modelling Mass Evolution in cosmological simulations: Radially

- Wechsler 2002 model (Example for M_{vir} 10^{12} $M_{\odot}$, a_c 0.15)



- Sometimes mass decreases at some (inner) radii
- Epoch of slow growth halfway
- Epoch of strong growth towards the end

Modelling Mass Evolution: Constraints

- Mass decrease at fixed radius: expected for major mergers
  - Not for smooth accretion and not far inwards

$$\frac{\dot{M}}{M} \geq 0 \; \forall \; r, t$$

- Hierarchical structure formations:
  - Galaxies/halos grow inside out
  - Accretion at the edge of the galaxy (r_{vir})
  - The further inwards, the less mass increase expected

$$\frac{d}{dr}\left(\frac{\dot{M}}{M}\right) \geq 0 \; \forall \; r, t$$ (or: growth timescale always larger outwards)

- Need a model that satisfies these properties

Alternative Mass Evolution Model

- Our model: evolution via *scale mass* $M_s(t)$ and *scale radius* $r_s(t)$

Mass Profile	Time derivative
$M(r,t) = M_s f(r/r_s)$	$\frac{\dot{M}}{M} = \frac{\dot{M}_s}{M_s} - \kappa(r/r_s)\frac{\dot{r}_s}{r_s}$ $\kappa(x) = \frac{d \log f}{d \log x}$

  - Logarithmic slope $\kappa(x)$: monotonously decreasing, postive function
  - Maximum value κ_{max} : 2.0 for NFW, 3.0 for Isochrone

- Use a power law relation: $M_s \propto {r_s}^{\gamma}$

  (Also suggested by Zhao et al 2003a,b, 2009)

$$\frac{\dot{M}}{M} = \frac{\dot{M}_s}{M_s}\left(1 - \frac{\kappa(r/r_s)}{\gamma}\right)$$

$\gamma \geq \kappa(r/r_s)$: No mass decrease at r

$\gamma \geq \kappa_{max}$: No mass decrease

Alternative Mass Evolution Model

- Inside out growth?

$$\frac{d}{dr}\left(\frac{\dot{M}}{M}\right) = -\frac{\dot{M}_s}{M_s}\frac{d}{dr}\kappa(r/r_s) \geq 0$$ <u>always in this model!</u>

- Choice for the evolution of scale mass
  - Scale mass is set

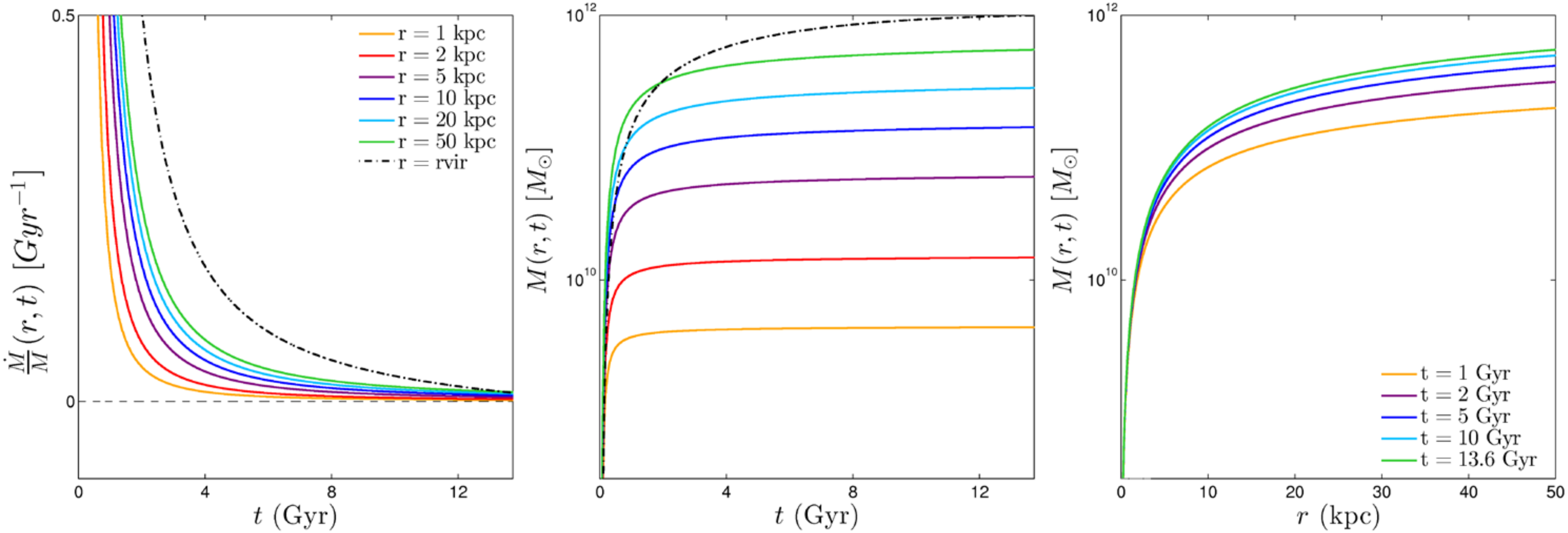
    $$M_s(t) = M_{s,O}\exp\left[-2a_g(z - z_O)\right]$$

  - And scale radius from power law relation:

    $$r_s(t) = r_{s,O}\exp\left[-2\frac{a_g}{\gamma}(z - z_O)\right]$$

Alternative Model: Results

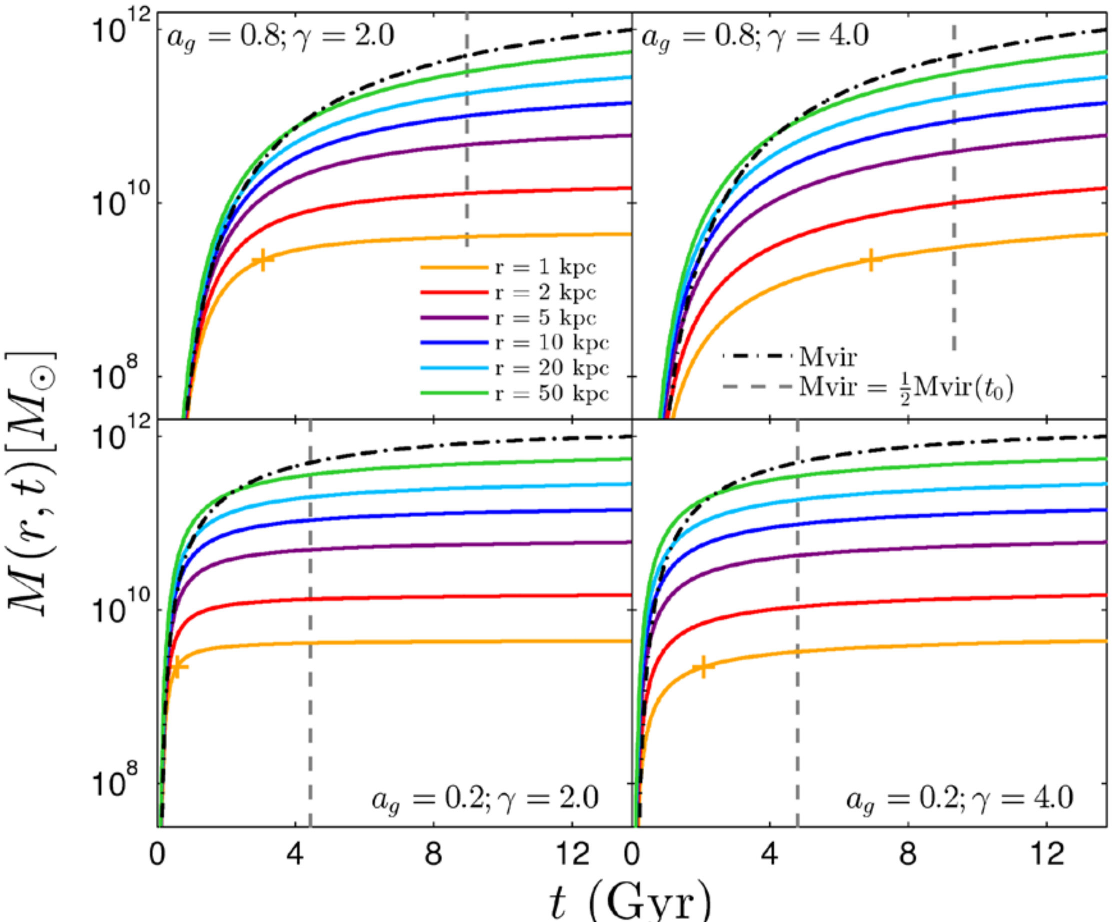
- Same final halo but with our model:



- No mass decrease (if wanted)
- No halfway slowing down and speeding up
- Always inside-out growth

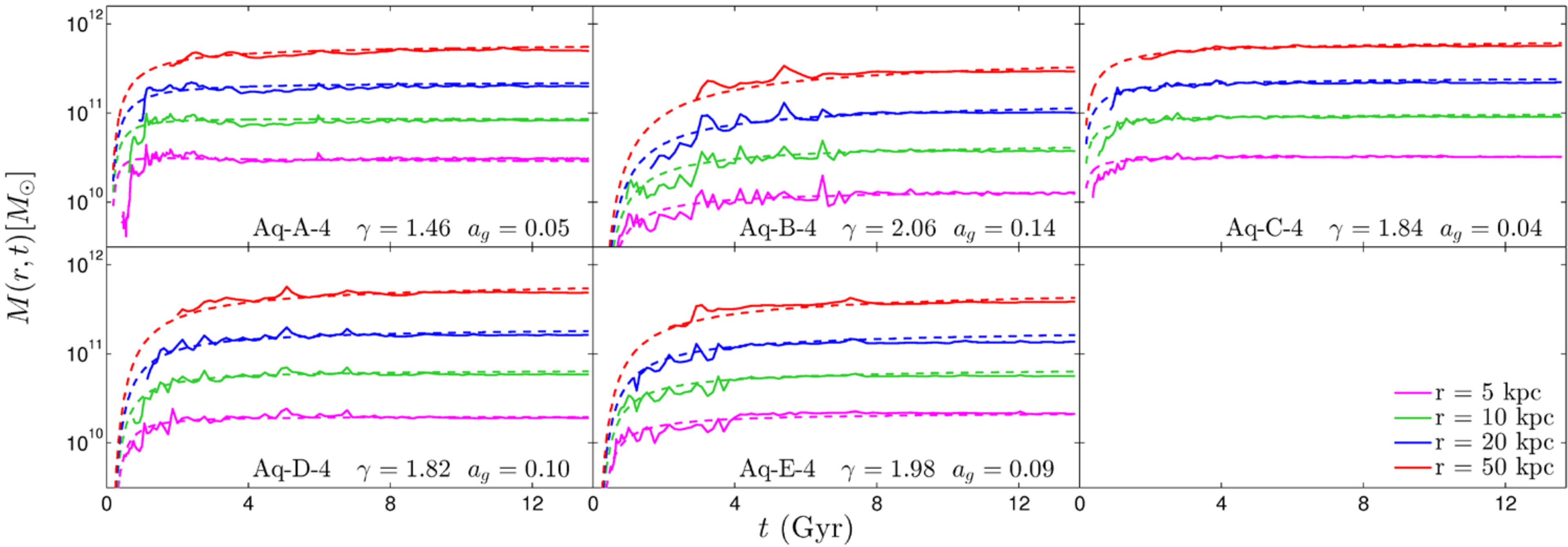
Alternative Model: Results

- Growth parameter a_g sets overall growth (M_{vir})
- Power law slope γ sets growth of shells



Alternative Model: Results

- Comparison with Aquarius simulations (Halo A-E)



- Note: $\gamma < 2$ for the best fit, but compatible with $\gamma = 2$

Alternative Model: Results

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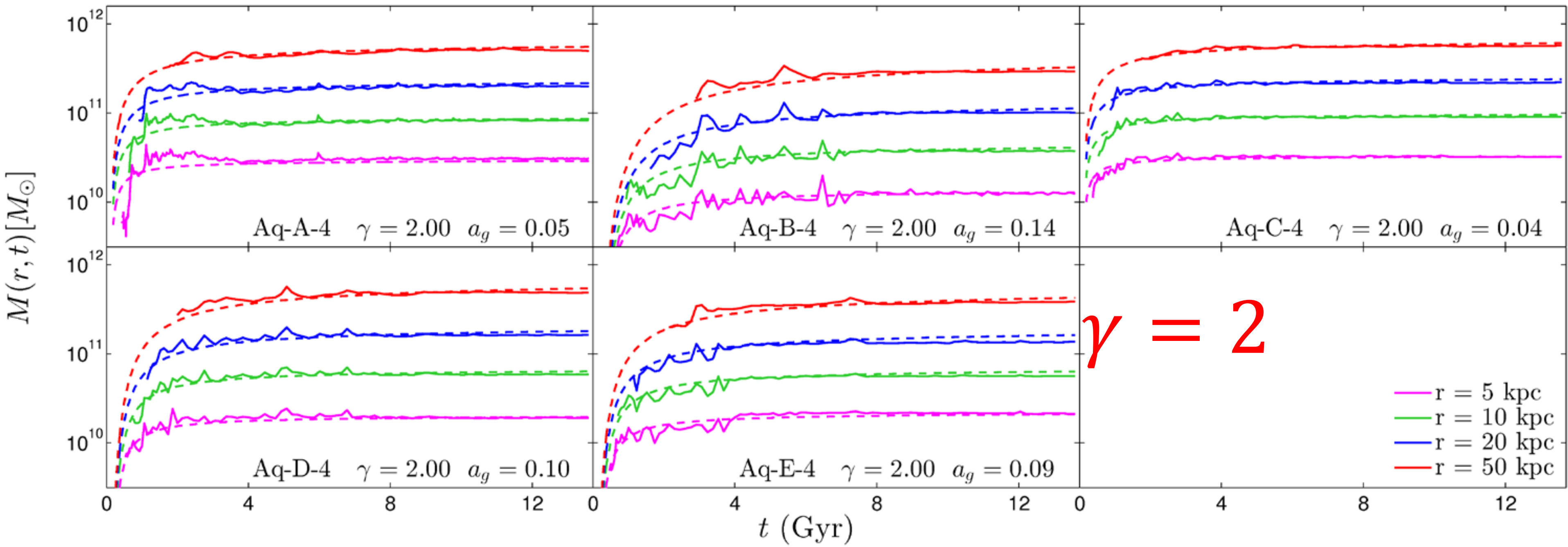
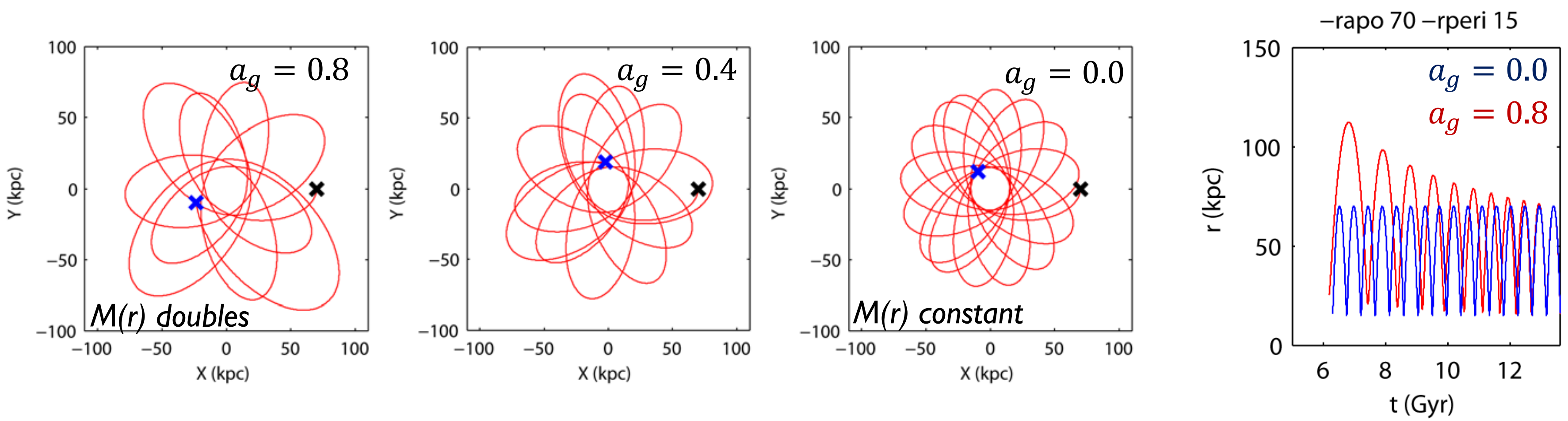


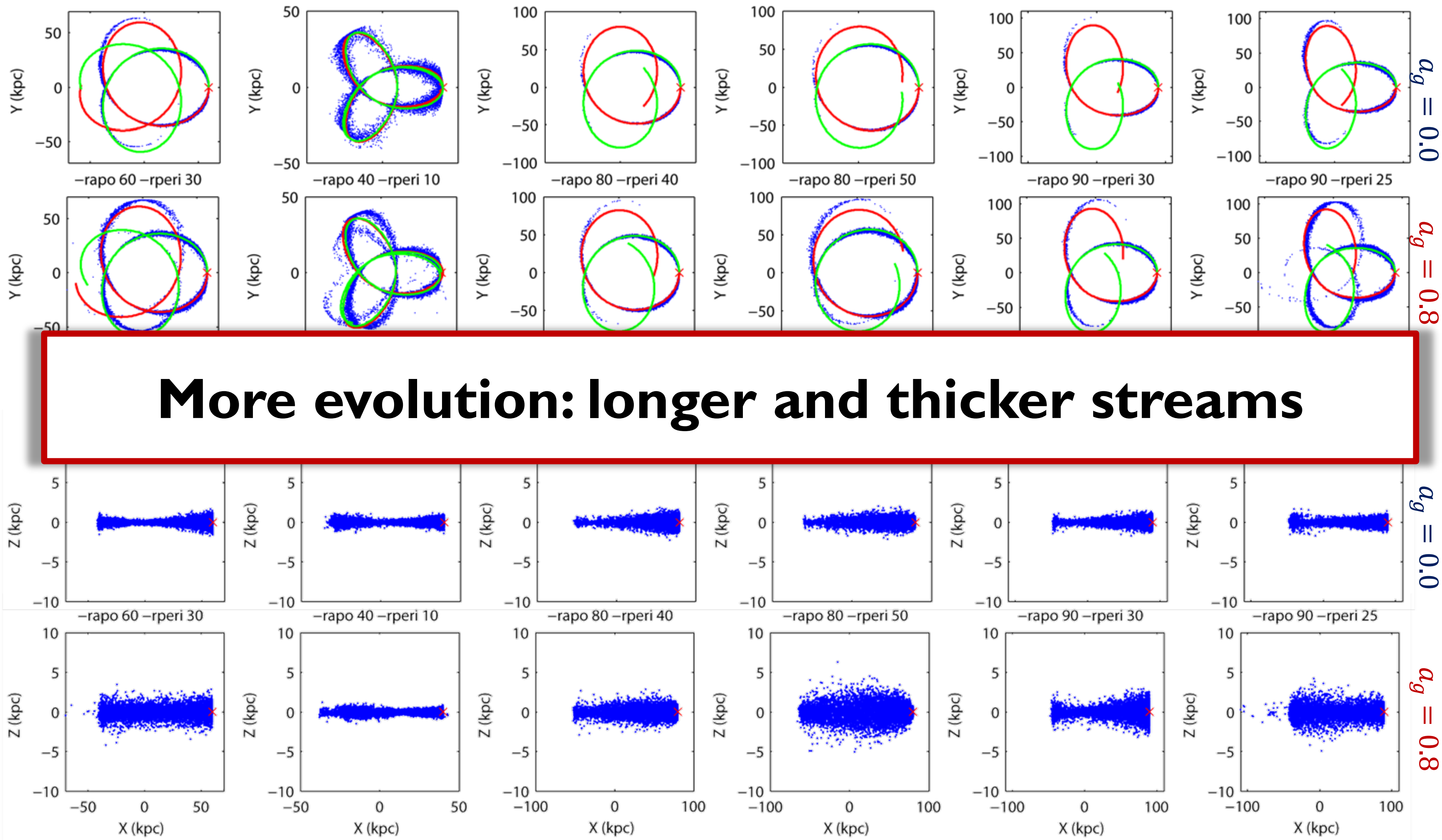
- Note: $\gamma < 2$ for the best fit, but compatible with $\gamma = 2$

Evolution of Streams in the Model

- Simulation setup:
  - Testparticles from 6D-multivariate gaussian DF in (x,v) are evolved in different time-dependent potentials
    - "Sculptor" ($\sigma_x = 300$ pc; $\sigma_v = 10$ km/s)
    - "Carina" ($\sigma_x = 100$ pc; $\sigma_v = 5$ km/s)
  - Same final halo and position for 'central' orbit
  - Backwards integration central orbit for ~ 8 Gyr, start at a pericentre, then place particles (minor time-length difference)

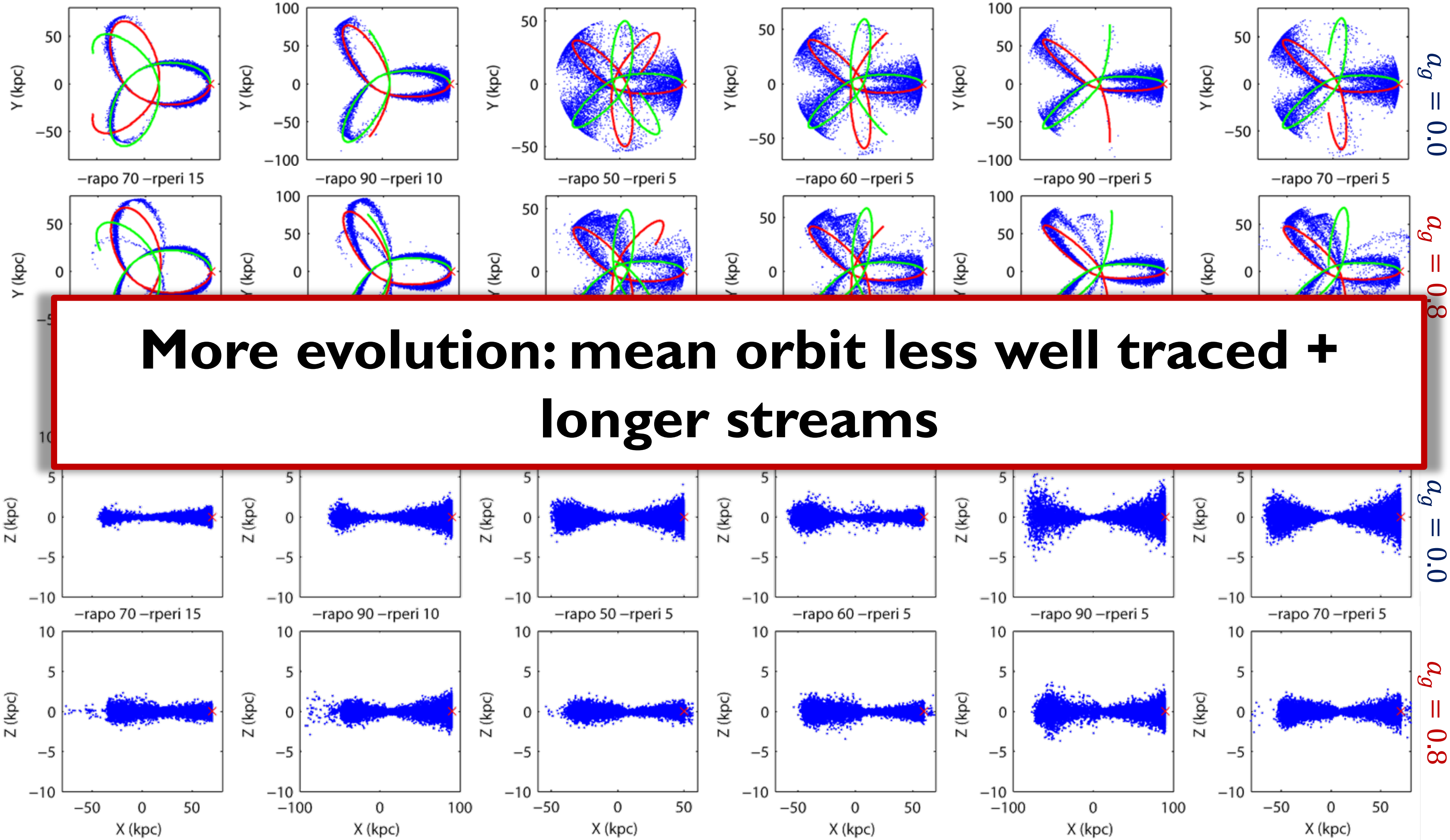


Evolution of Streams in the Model: More Circular Orbits (High L)



More evolution: longer and thicker streams

Evolution of Streams in the Model: More Radial Orbits (Low L)



More evolution: mean orbit less well traced + longer streams

Evolution of Streams in the Model

- Close to progenitor, stream approximately traces central orbit
  - Need only ~ 1-2 Gyr of central orbit to trace stream (v.s. 8 Gyr for stream)
  - Mostly sensitive to recent evolution (further from central orbit more evolution)
  - Mass for stream doubled in 8 Gyr, but for central orbit in 2 Gyr only 10-20%.

- Need long enough stream (~1-2 radial periods)

- More Circular Orbit
  - Stream does trace central orbit approximately
  - Biggest difference: Stream length and thickness
  - Relative spread in energy is higher for evolving case: longer/thicker stream

- Radial Orbit (rapo/rperi > 9)
  - Biggest difference: Central orbit traces stream much worse in evolving case

Summary

- Wechsler model not physical at all radii when modelling behaviour of individual halos
- Using r_s and M_s with a power-law relation constrains evolution better
- An exponential in z for M_s gives resonable fits to simulations
- Properties of streams are different when the host potential is time-dependent