



Schwarzschild modelling with multiple stellar population constraints

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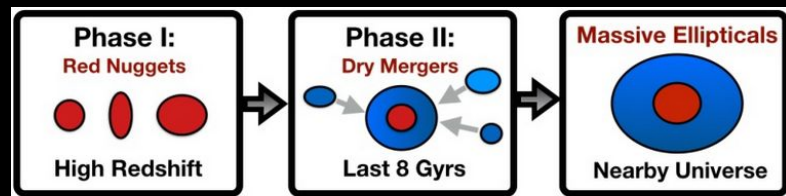
Introduction: From “Red and dead” to rich formation histories



Credit: ESA/Hubble & NASA, C. Sarazin et al.
Messier 105 (NGC 3379)



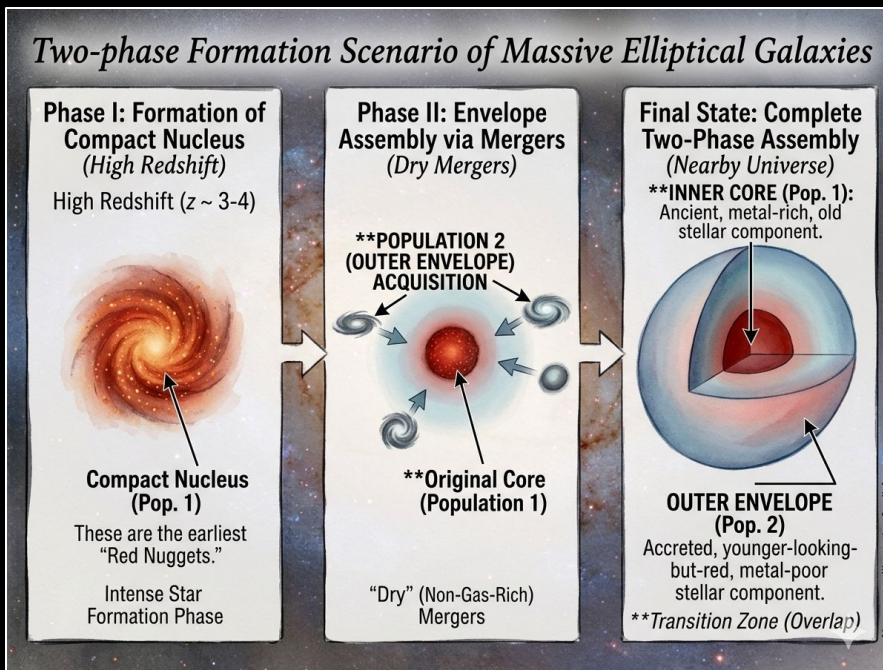
Introduction: From “Red and dead” to rich formation histories



Song Huang et al. 2016



Credit: ESA/Hubble & NASA, C. Sarazin et al.
Messier 105 (NGC 3379)



“Gemini Nano Banana 2026”

Motivation: M/L Gradients in Massive ETGs

Recent dynamical models reveal centrally increasing **dynamical mass-to-light (M/L) ratio gradients** in massive early-type galaxies.

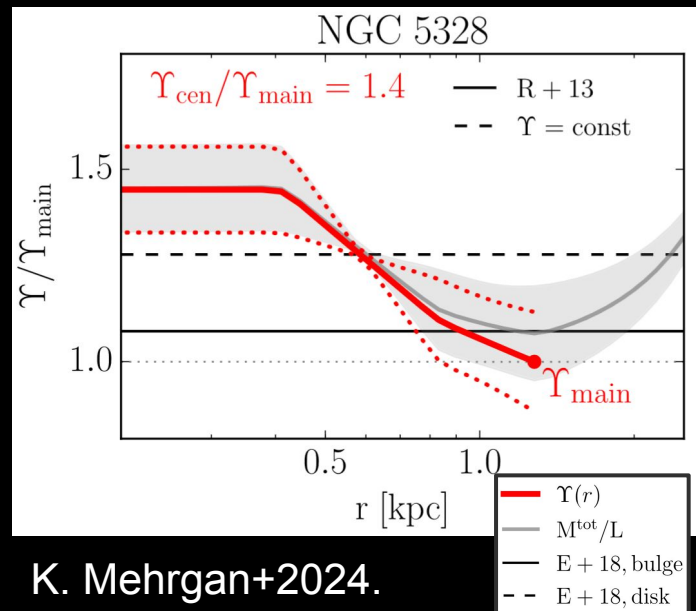
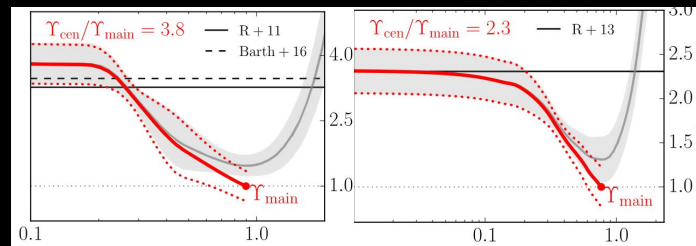
What causes the central M/L increase?

- Radial IMF variations?
- Centrally concentrated dark matter?
- **Superposition of distinct stellar populations?**

Two-phase formation scenario

In-situ core (old, high M/L) + ex-situ envelope (younger, lower M/L)
 → Natural radial M/L gradient from superposition?

→ *Need a dynamical model that handles multiple stellar populations independently to test this.*



K. Mehrgan+2024.

“Dynamical Stellar Mass-to-light Ratio Gradients: Evidence for Very Centrally Concentrated IMF Variations in ETGs?”



Mock Data

N-body properties, observables
and spectral decomposition



Mock Galaxy: Intrinsic properties for two-component system.

Component 1 = Inner “in-situ” $Y_1=5.25$
Component 2 = Outer “ex-situ” $Y_2=3.31$

Panels (intrinsic properties) :

(a) Stellar mass density profiles

(b) Stellar M/L gradient: $Y_1=5.25 \rightarrow Y_2=3.31$

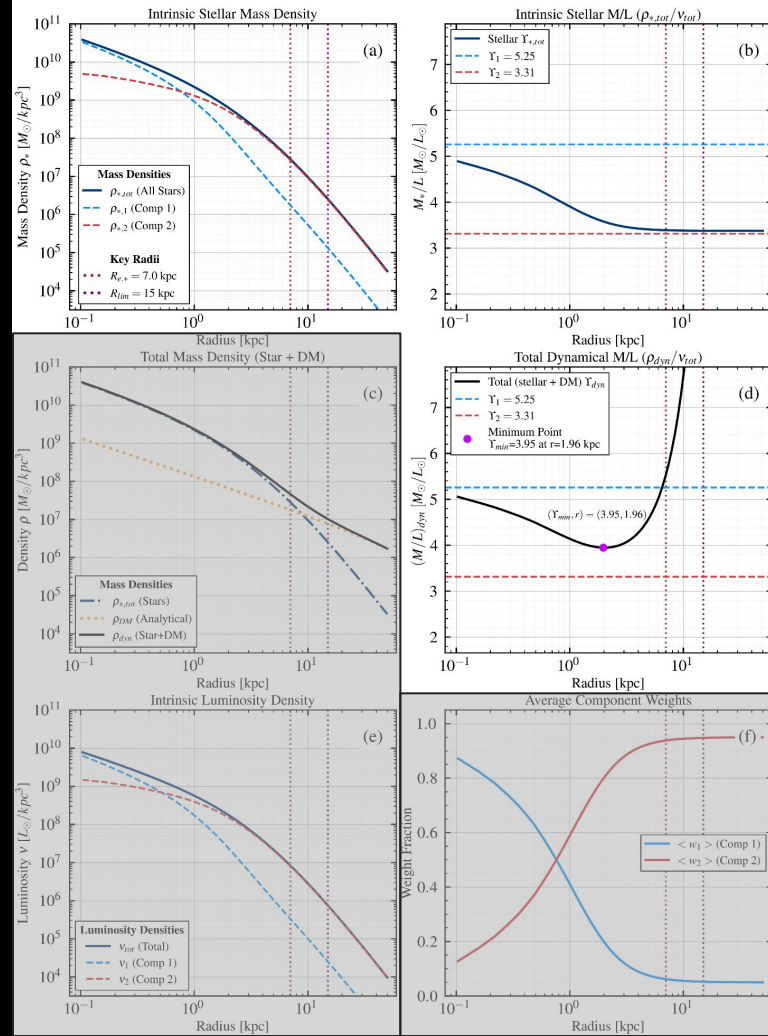
(c) Total mass (stars + DM)

(d) Dynamical M/L: U-shape!

(e) Luminosity densities

(f) Component weight fractions

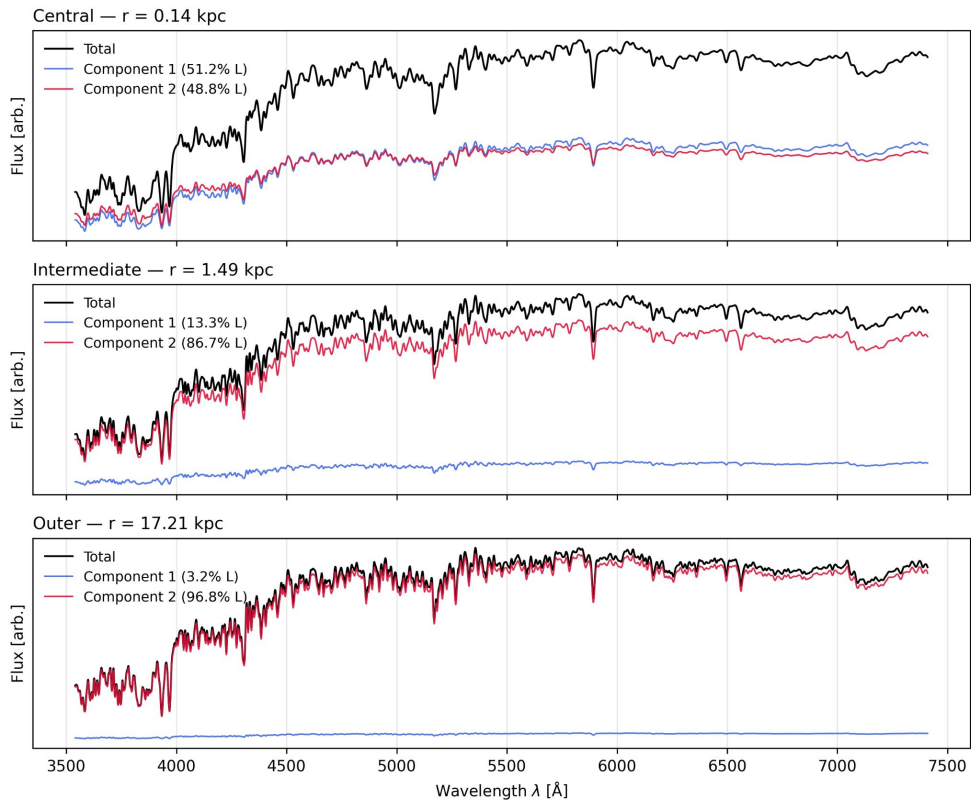
Intrinsic Properties of N-body Realisation
 $N_s=1.0e+08 \parallel Y_1=5.255 \parallel Y_2=3.311$



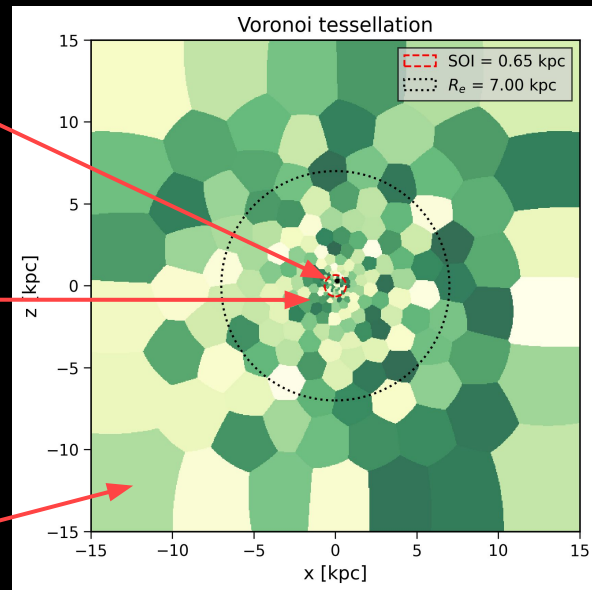


Mock Spectra: A Superposition of Components

Decomposed projected mock spectra at different galactocentric radii



N-body data projected onto sky plane, and then Voronoi tessellated.





Method

New multi-component Schwarzschild dynamical modelling

Framework: **MOSAIC**

MOSAIC = **M**ulti-component **O**rbit-superposition **S**chwarzschild
Analysis of **I**nternal **C**omponents



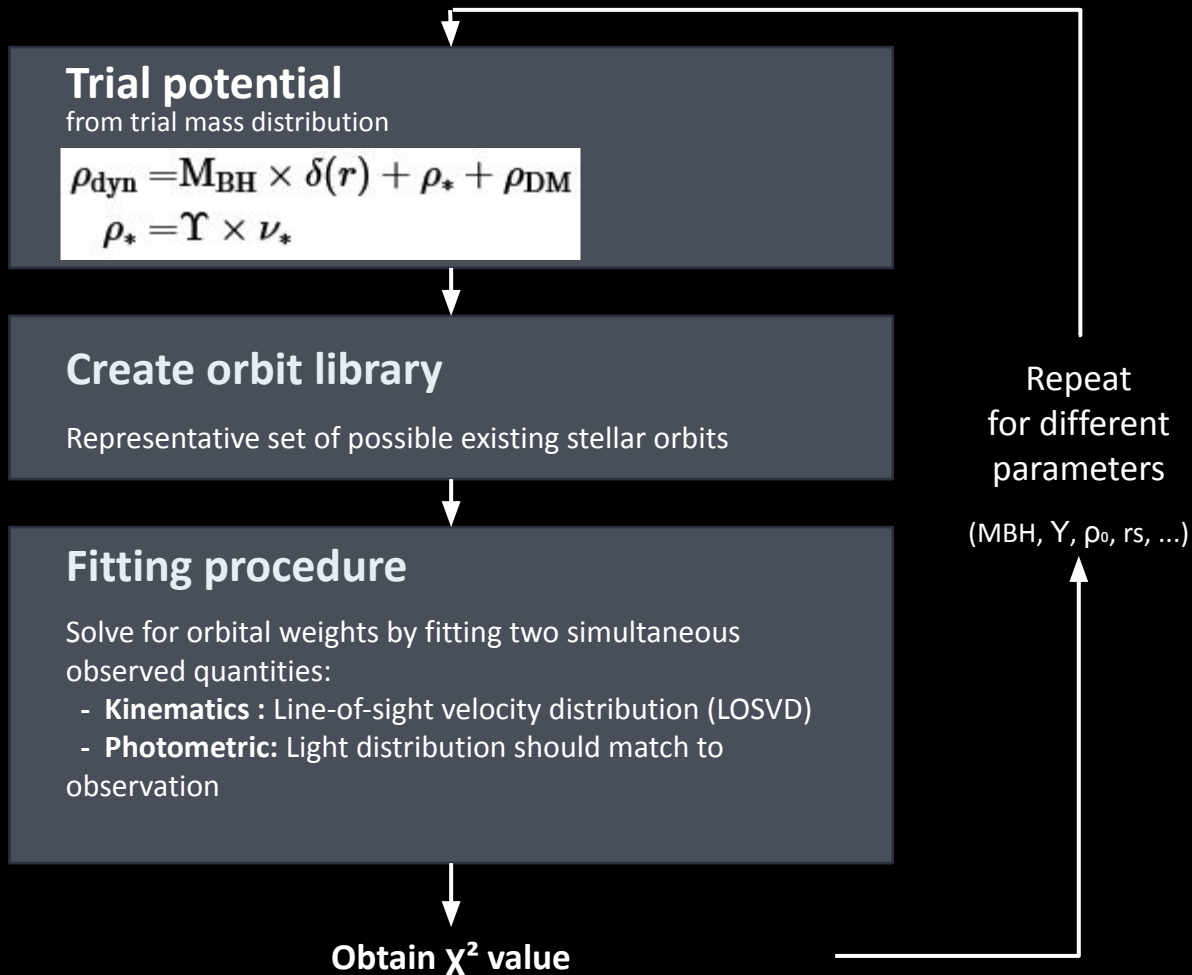
Schwarzschild Method:

Quick overview of "classical model"

Schwarzschild (1979)

Galaxy = collisionless, steady-state system

DF depends on integrals of motion (E, L_z, I_3)





Schwarzschild Method:

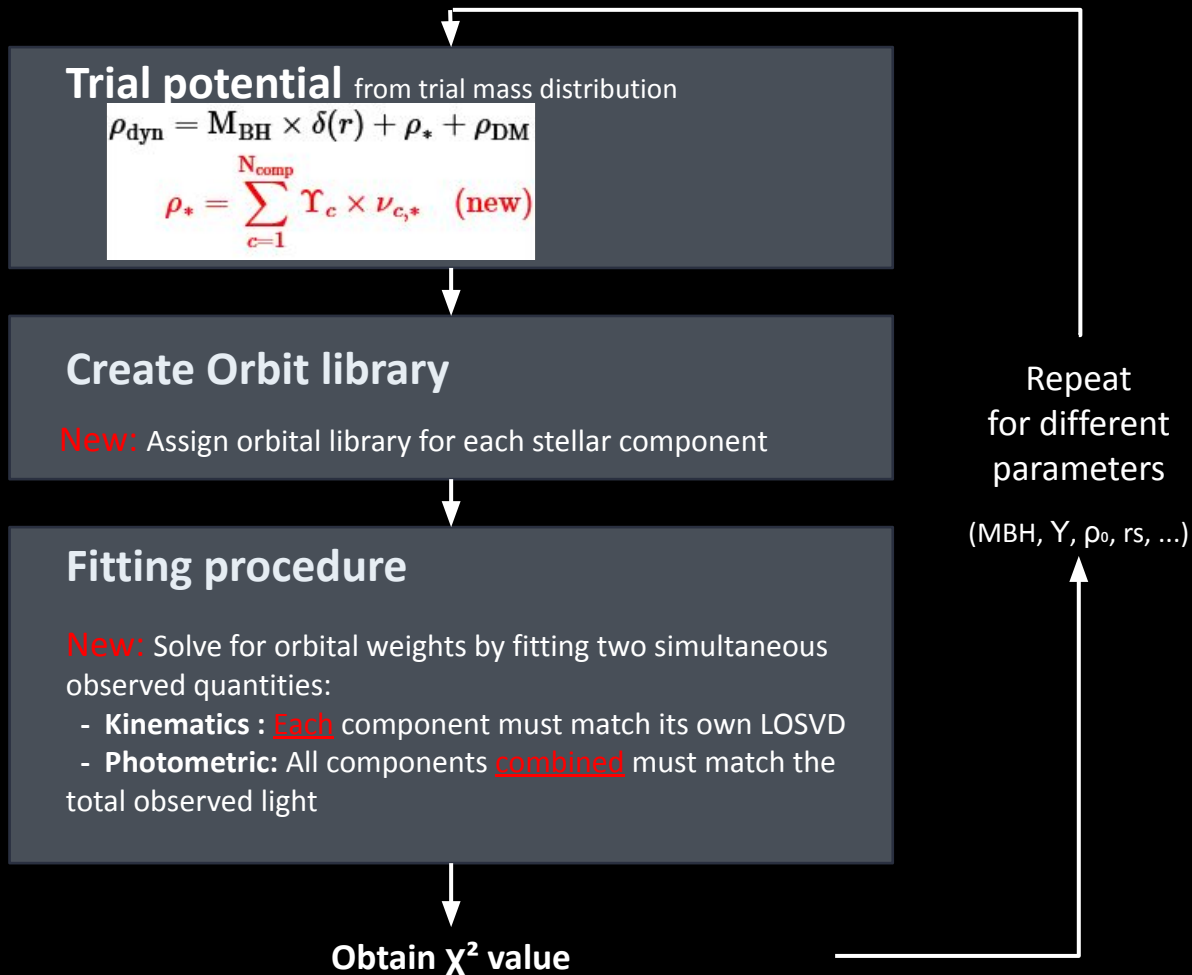
Quick overview of “multi-component model” (MOSAIC)

Schwarzschild (1979)

Galaxy = collisionless, steady-state system

DF depends on integrals of motion (E, L_z, I_3)

New method: Instead of a single DF, we have multiple DFs which are superposed/summed





Results

Projected properties
Intrinsic properties



Results: Projected Kinematic Recovery

Component-resolved fit

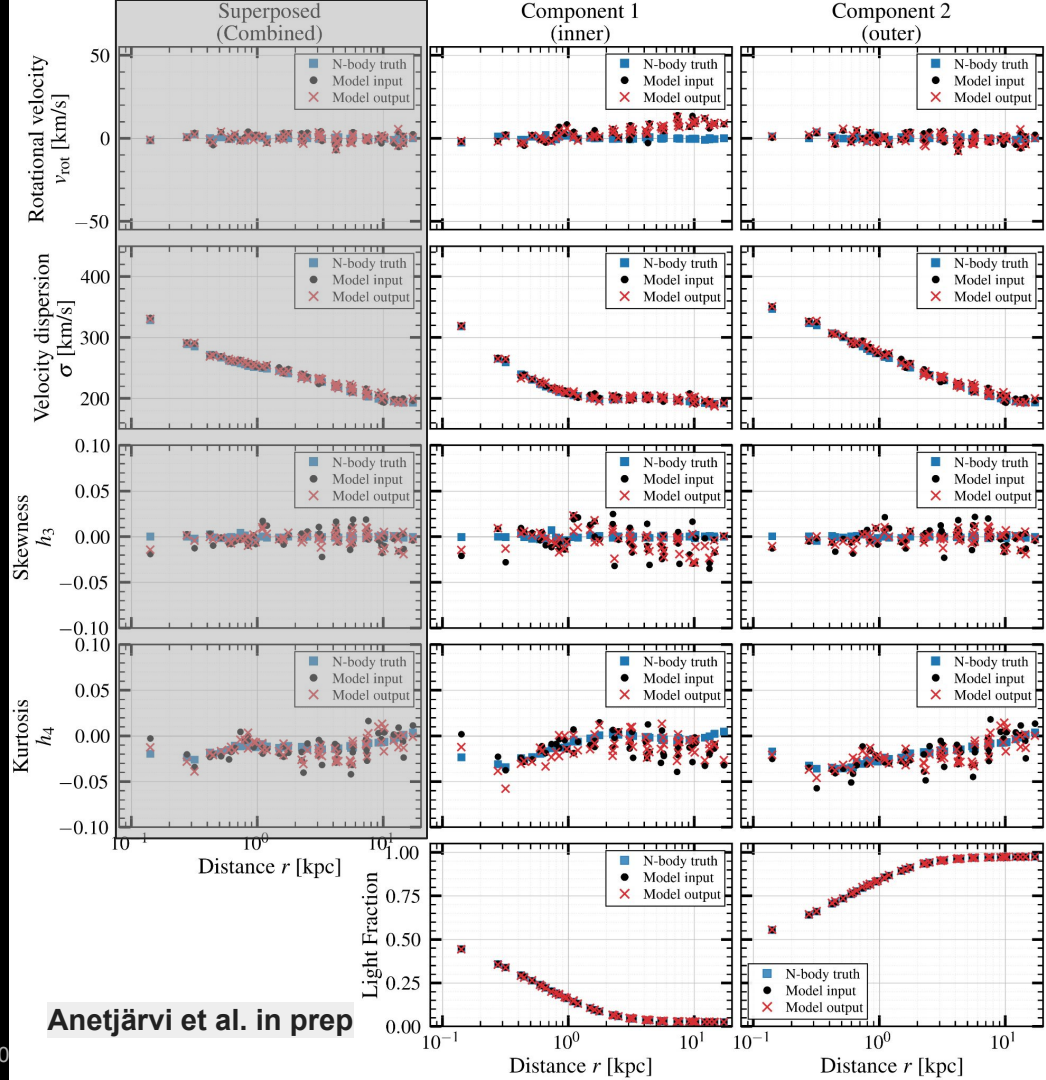
Symbols

- N-body truth
- Model input (WINGFIT)
- × Model output

Rows: v_{rot} , σ , h_3 , h_4 , light fraction

Columns: Superposed | Comp 1 | Comp 2

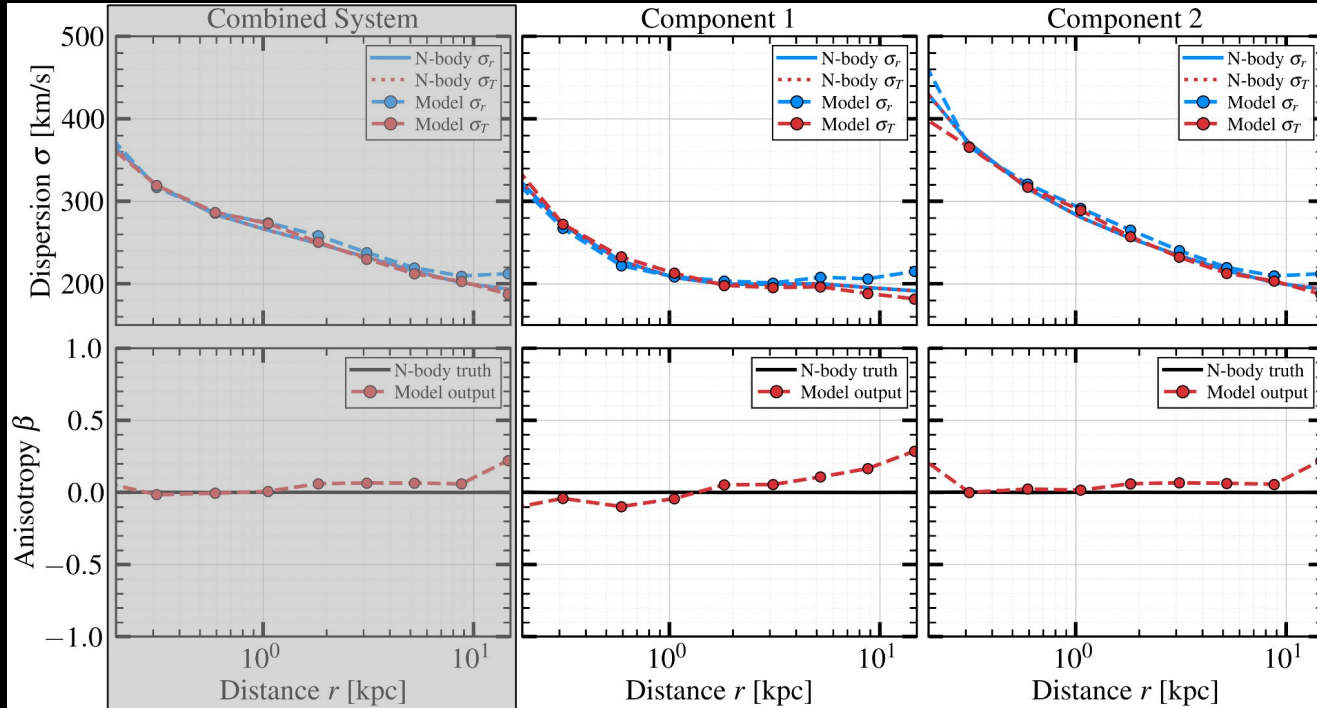
Key: multi-component model is able to simultaneously fit multiple component kinematics



Anetjärvi et al. in prep

MPE Results: Intrinsic Properties

Velocity dispersions & Anisotropy parameter



Anisotropy parameter

$$\beta(r) = 1 - \frac{\sigma_T^2(r)}{2\sigma_r^2(r)}$$

Tangential component

$$\sigma_T^2 = \sigma_\theta^2 + \sigma_\phi^2$$

Anetjärvi et al. in prep



Key Result: Intrinsic Density & M/L Recovery

Central results:

(a) Component mass densities recovered

(b) Smooth stellar M/L gradient reproduced:

$$Y_1 = 5.25 \rightarrow Y_2 = 3.31$$

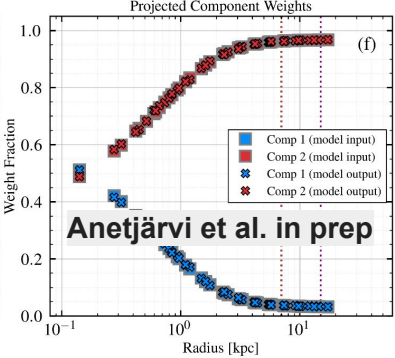
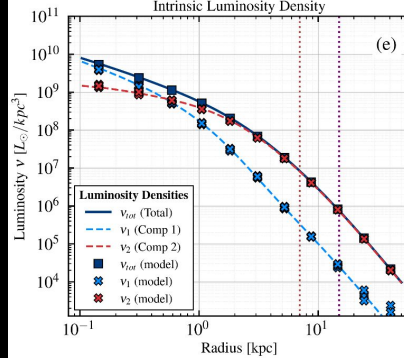
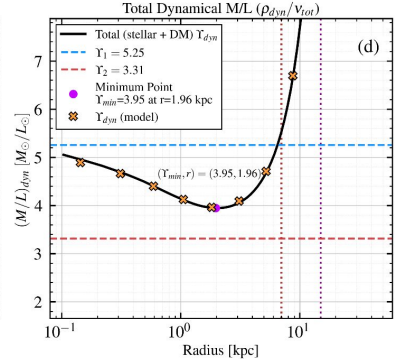
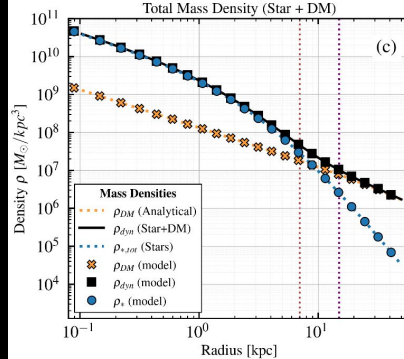
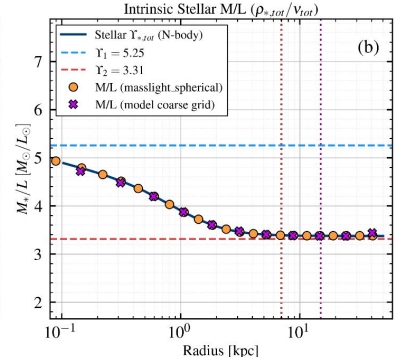
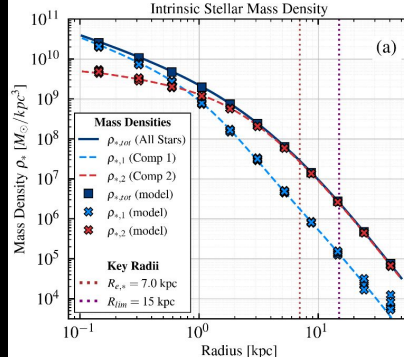
(c) Total mass profile correct

(d) U-shaped Y_{dyn} recovered

$$Y_{\text{dyn, min}} \approx 3.95 \text{ at } r \approx 2 \text{ kpc}$$

(e) Luminosity decomposition

(f) Component weights match





Summary & Thank you!

Summary

Introduced new multi-component Schwarzschild modelling framework **MOSAIC**

- arbitrary number of stellar components with independent M/L

Model recovers:

- Projected kinematics (V , σ , h_3 , h_4) per component
- Intrinsic 3D velocity structure per population
- Intrinsic density partition & stellar M/L gradient
- **U-shaped dynamical M/L profile**

What this framework could allow as to do?

- Test if stellar subpopulations can explain observed central mass structures
- Determine the 3D orbital structures of subpopulations
- Derive more precise DM profiles through improved stellar mass modelling

Outlook

- Further error estimates
- Application to real galaxies
- **More details in paper Anetjärvi et al. (soon TM)**