The Connection between Simulations, Dynamical Models and Observations

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ArcheoDyn

Observations

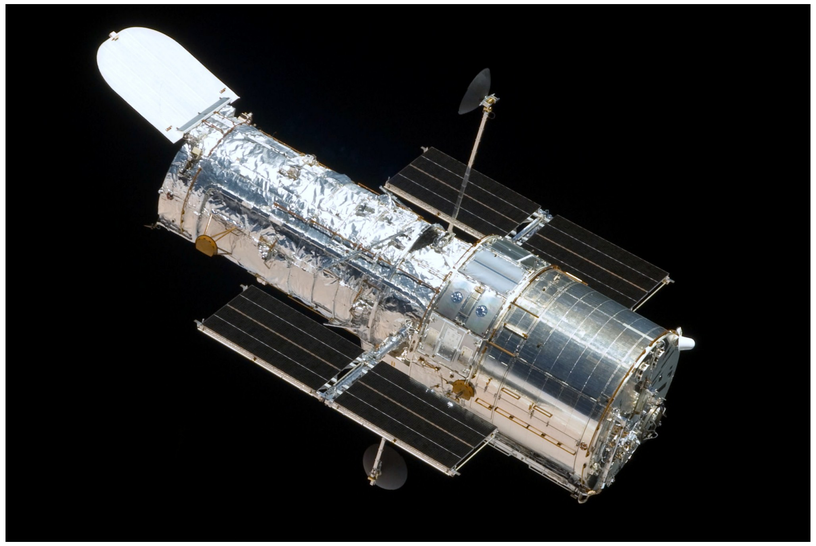
Dynamical Models

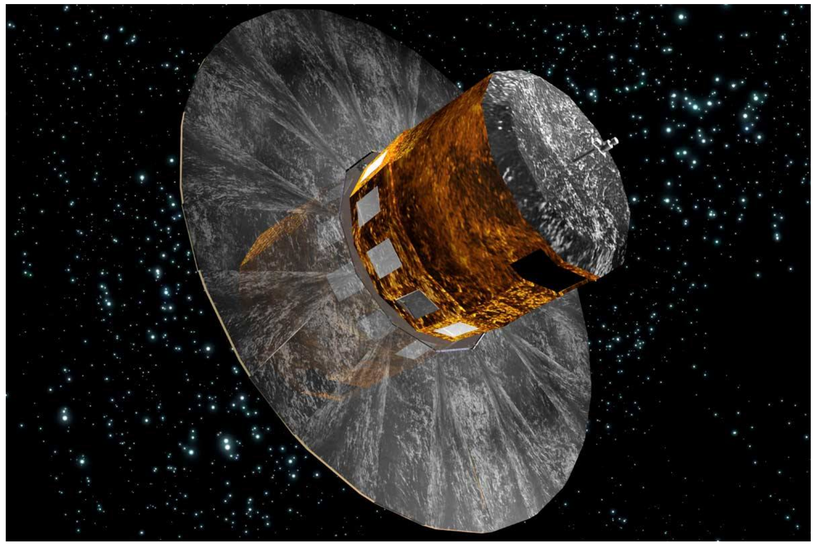
N-body Simulations

Observations

current state of the cluster

Observations: Kinematics





line-of-sight velocities

e.g. Kamann+ 2018, Baumgardt+ 2018

HST

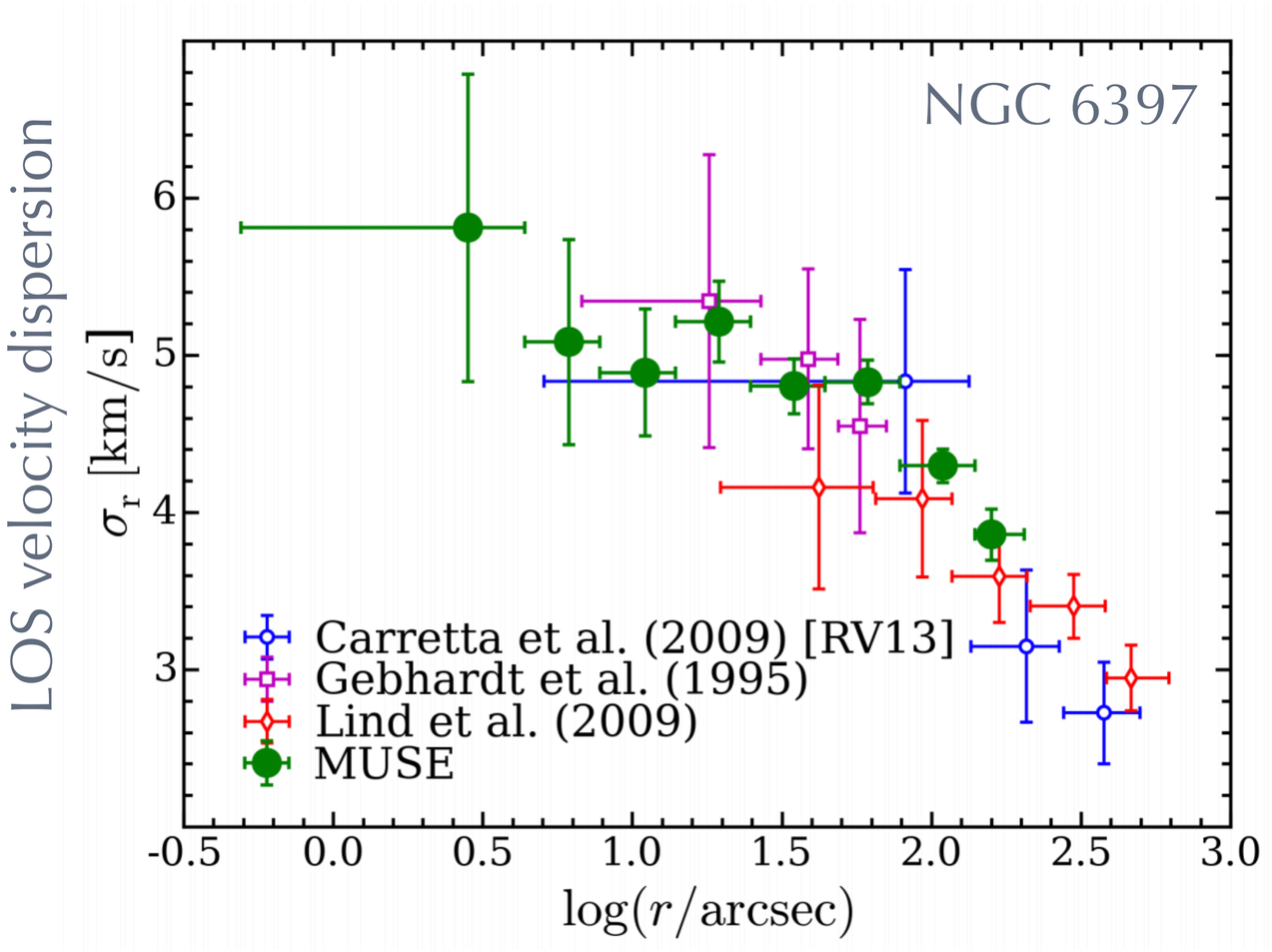
e.g. Bellini+ 2014, Libralato+ 2018

proper motions

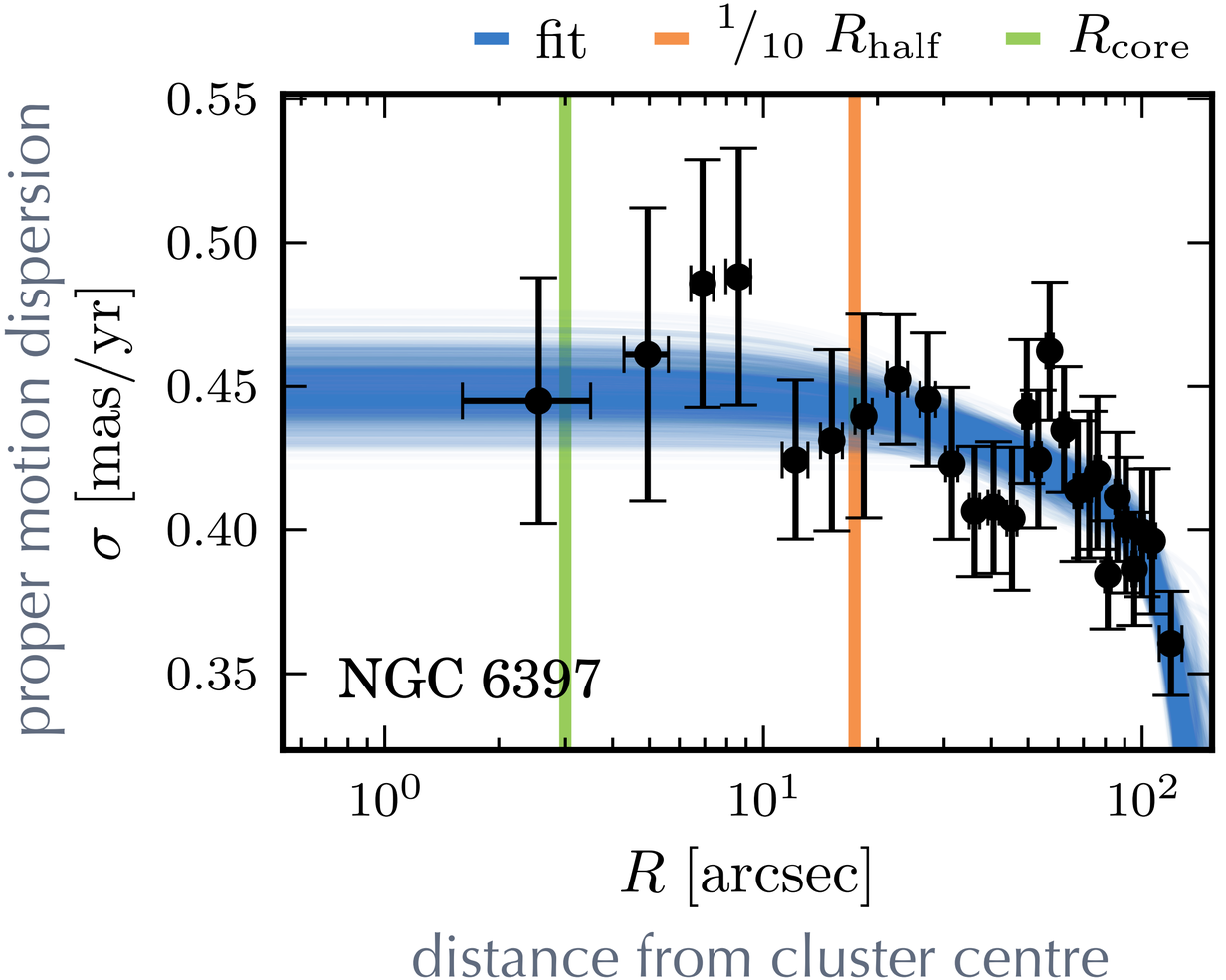
Gaia

e.g. Baumgardt+ 2019

Kinematics: Velocity Dispersions



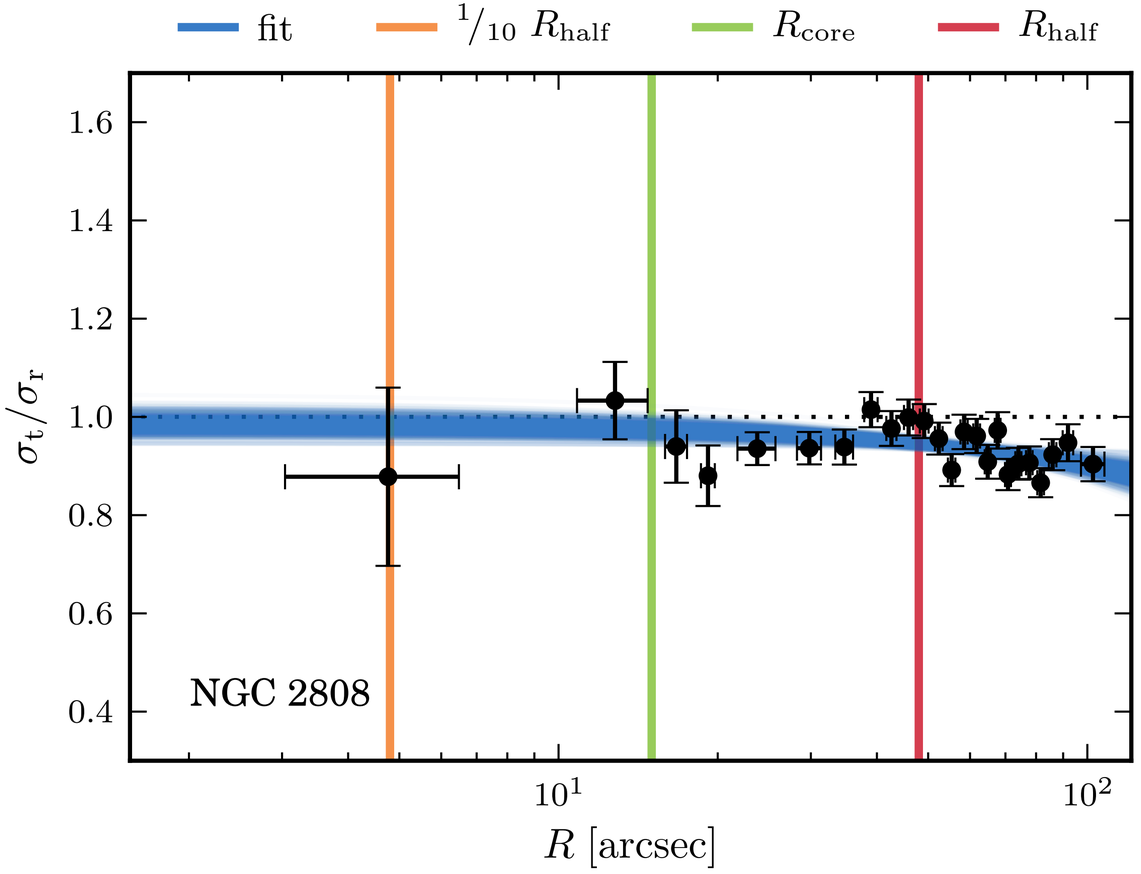
Kamann+ 2018



Watkins+ 2015a

Kinematics: Anisotropy

anisotropy on the plane of the sky



tangential

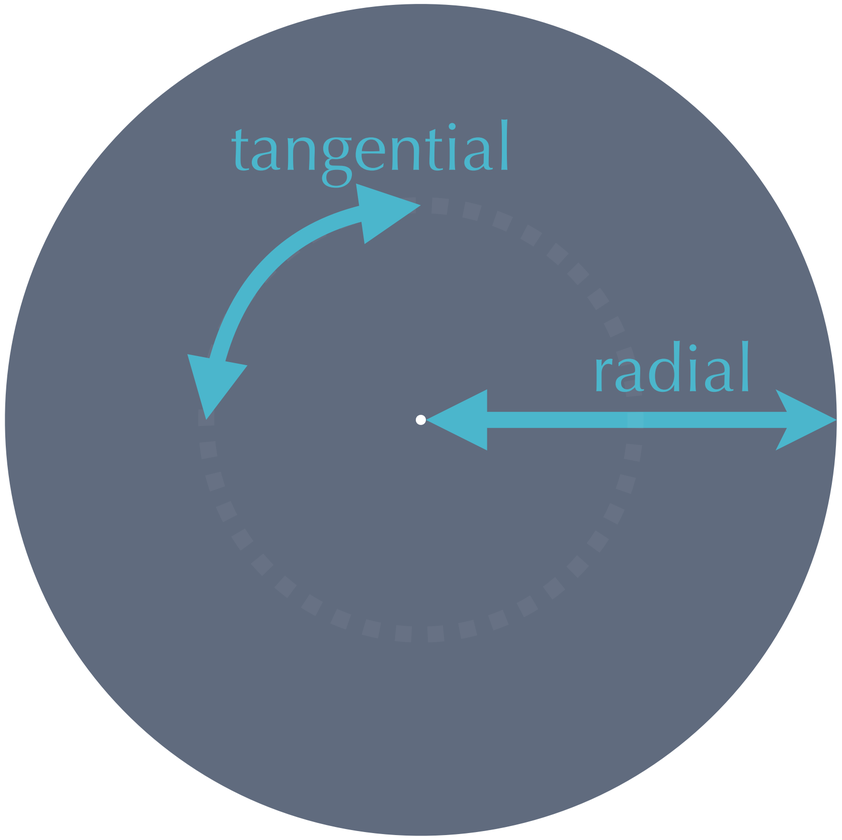
isotropic

radial

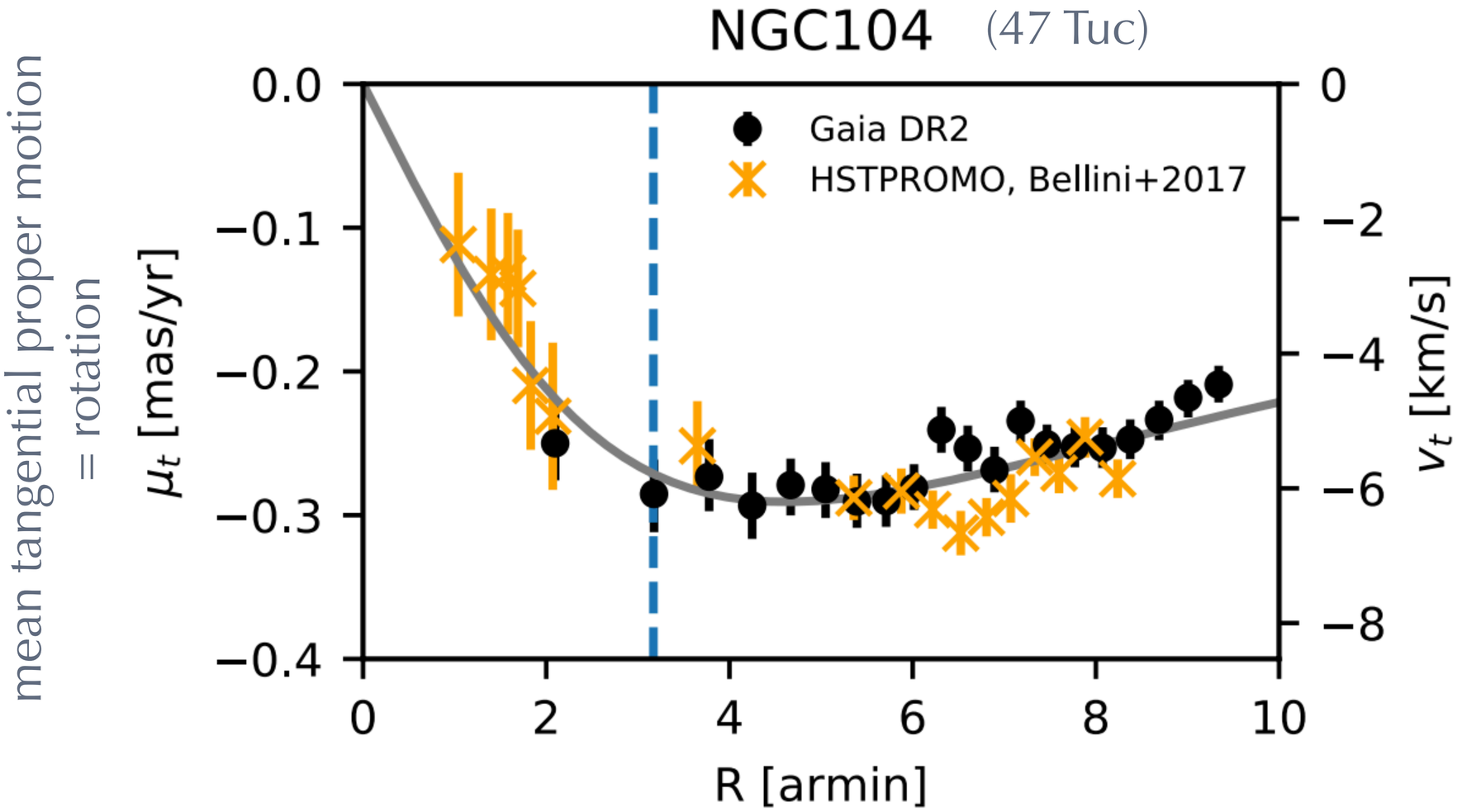
Watkins+ 2015a

$$\frac{\text{dispersion in direction A}}{\text{dispersion in direction B}}$$

(orthogonal directions)



Kinematics: Rotation

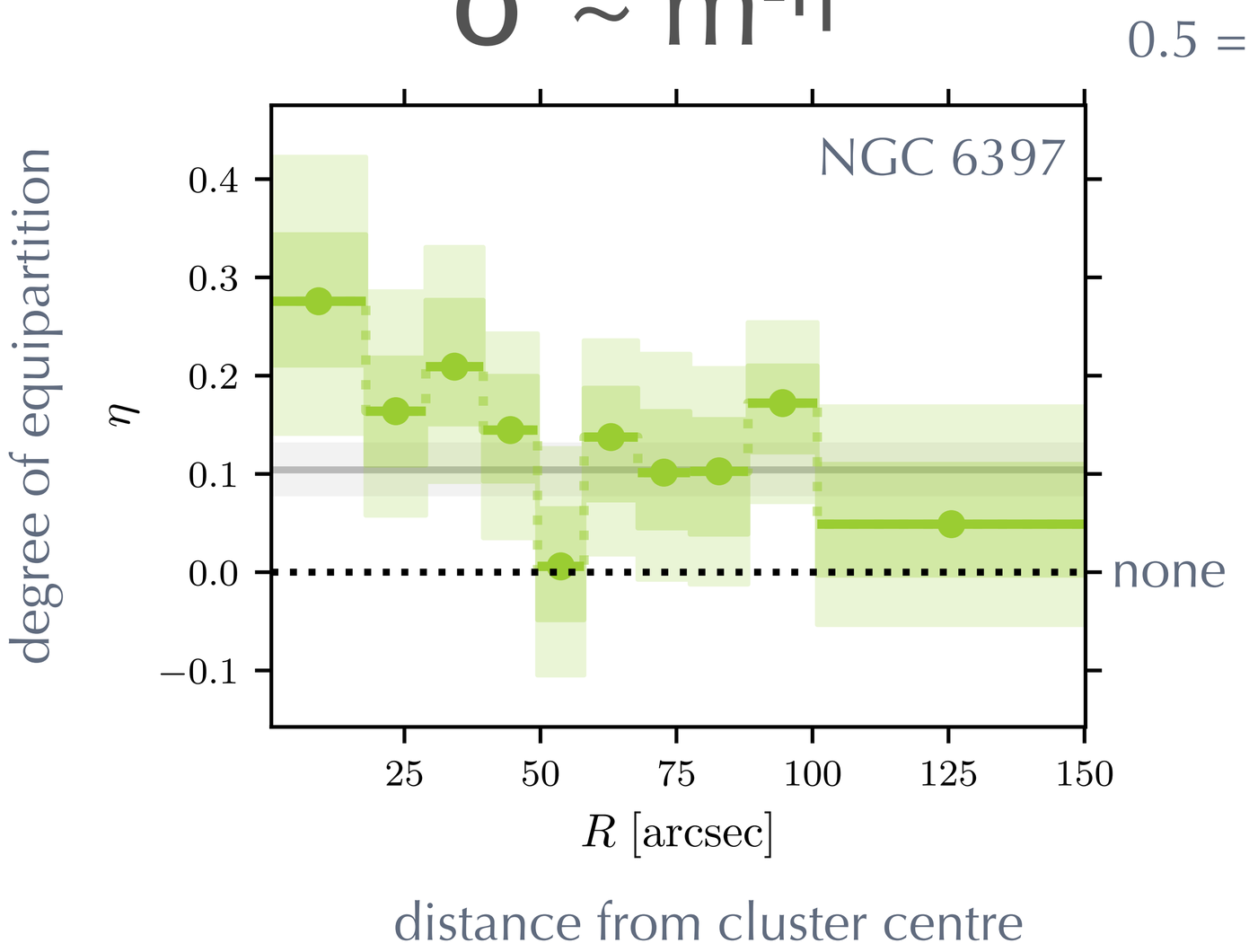


Bianchini+ 2018

distance from cluster centre

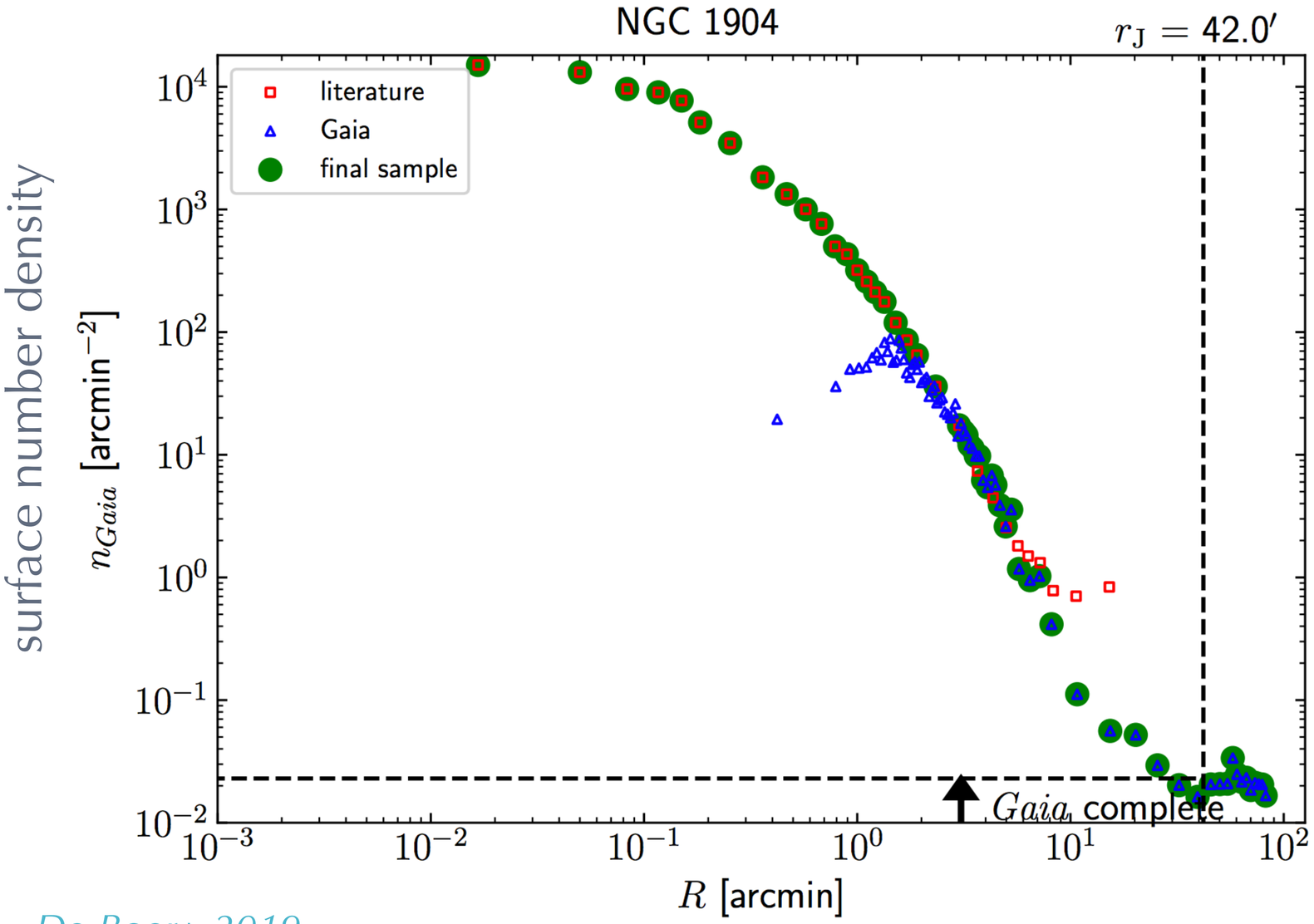
Kinematics: Energy Equipartition

$\sigma \sim m^{-\eta}$



Watkins+ in preparation

Observations: Number Density/Surface Brightness



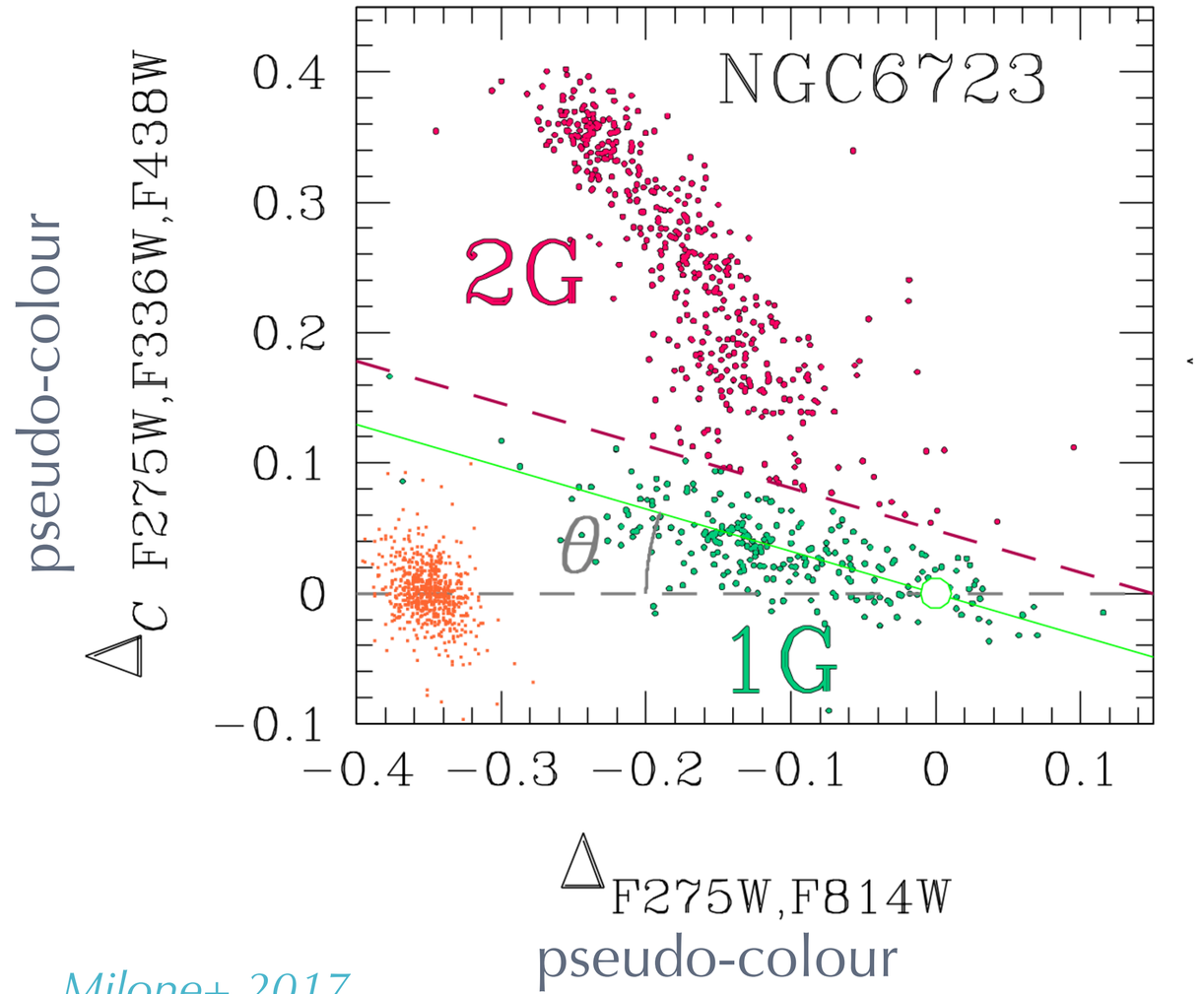
De Boer+ 2019

Spoilers:

!!

Dynamical Models

Observations: colours / abundances



Milone+ 2017

Dynamical Models

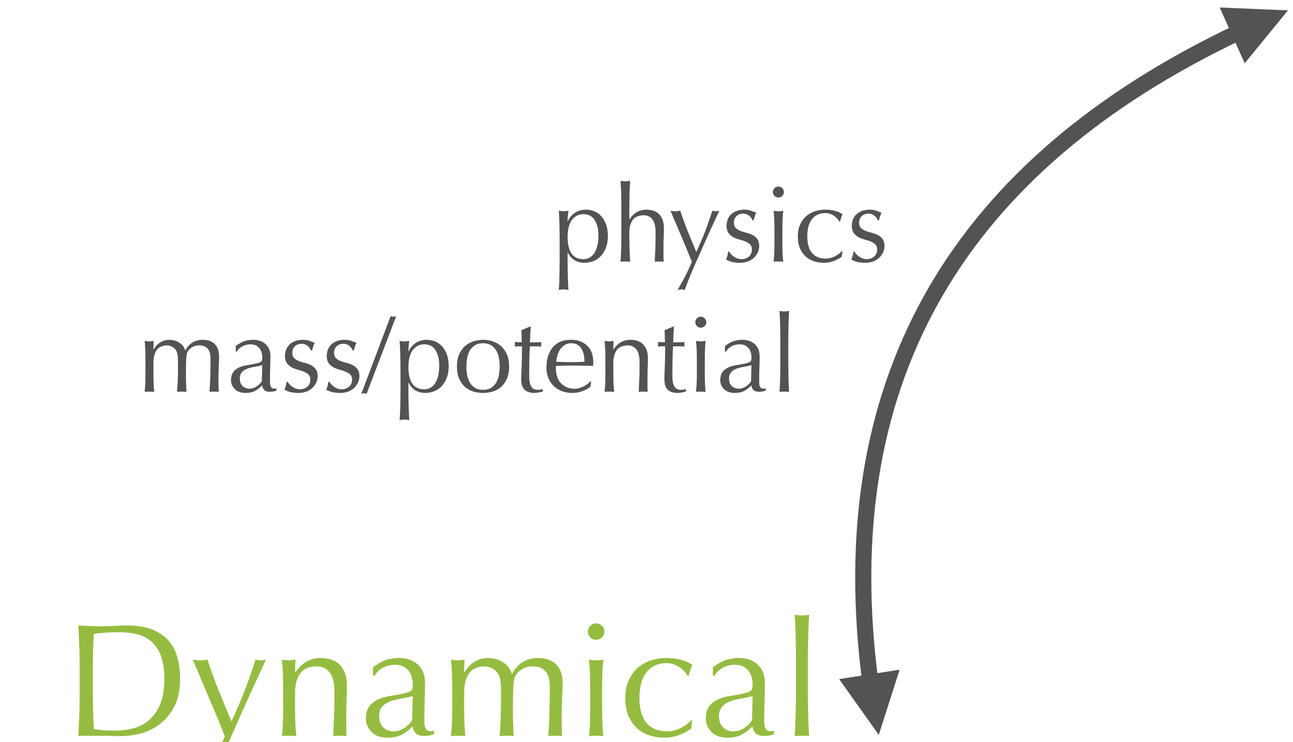
underlying physics:
why are stars moving as they are?

Dynamical Models: Different Flavours

Jeans	Distribution Function (DF)	Schwarzschild (orbit fitting)
Jeans equations	energy & angular momentum (or actions & angles)	orbits
~fast	~fast	SLOW
maybe unphysical	always physical	always physical

mass + tracer density ++ → kinematics

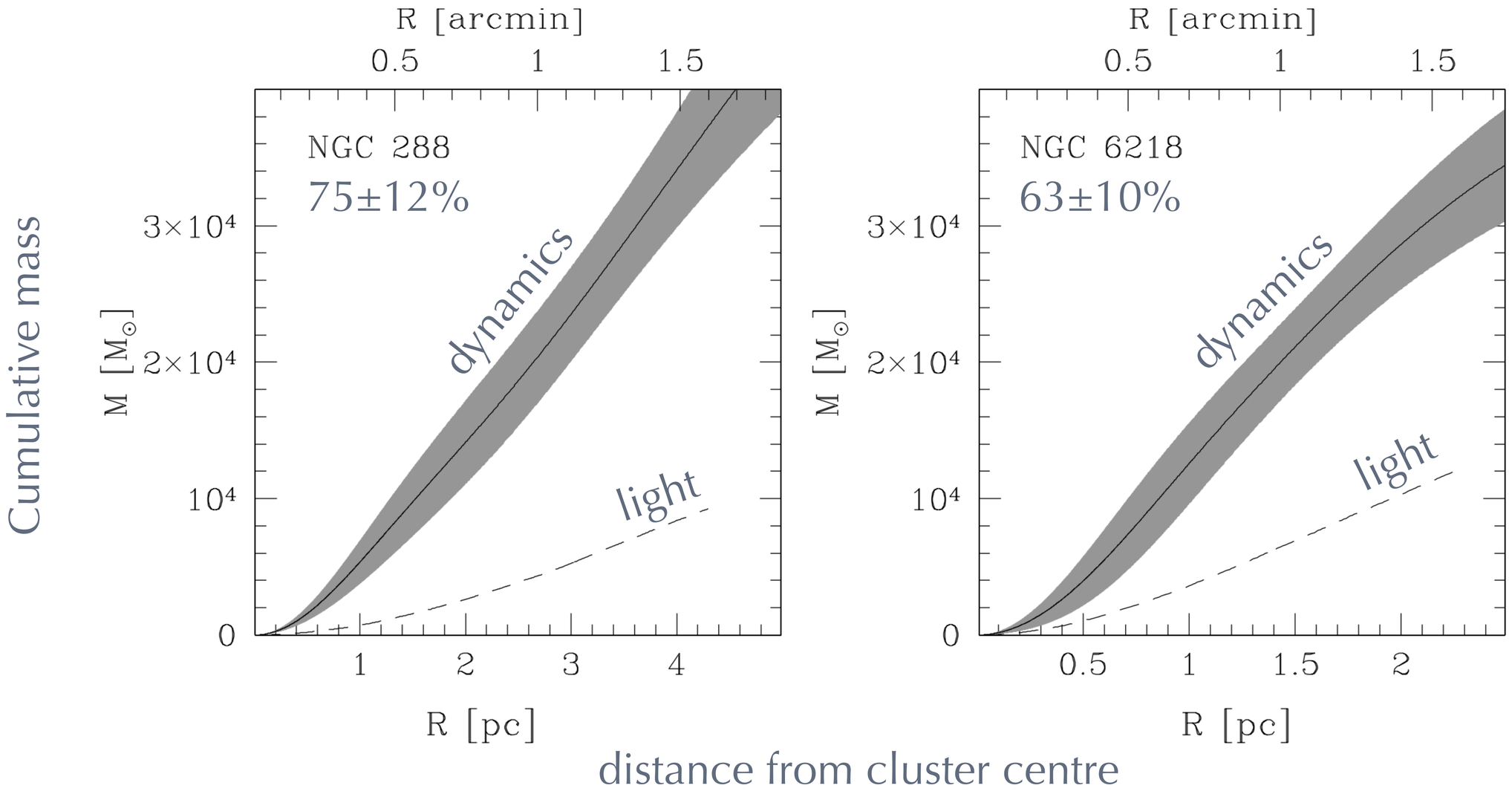
Observations



Dynamical Models

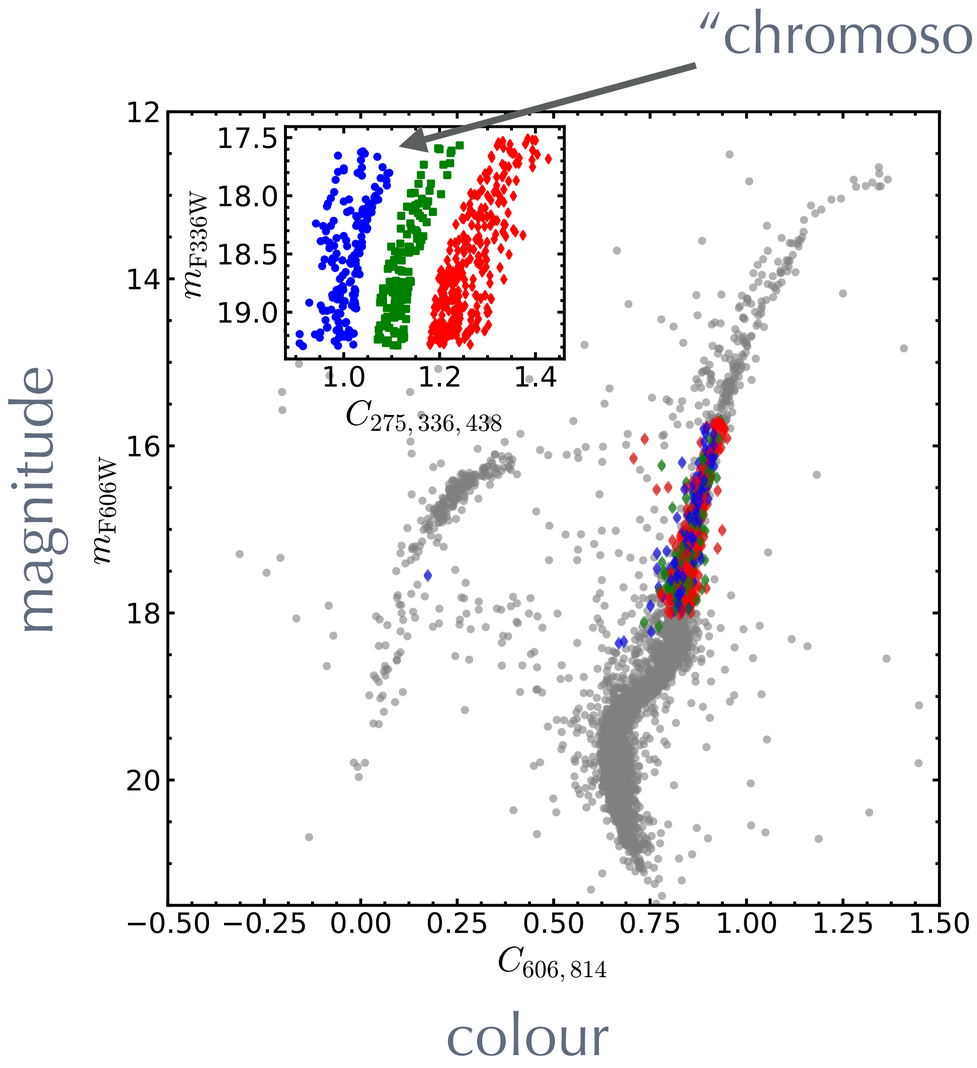
N-body Simulations

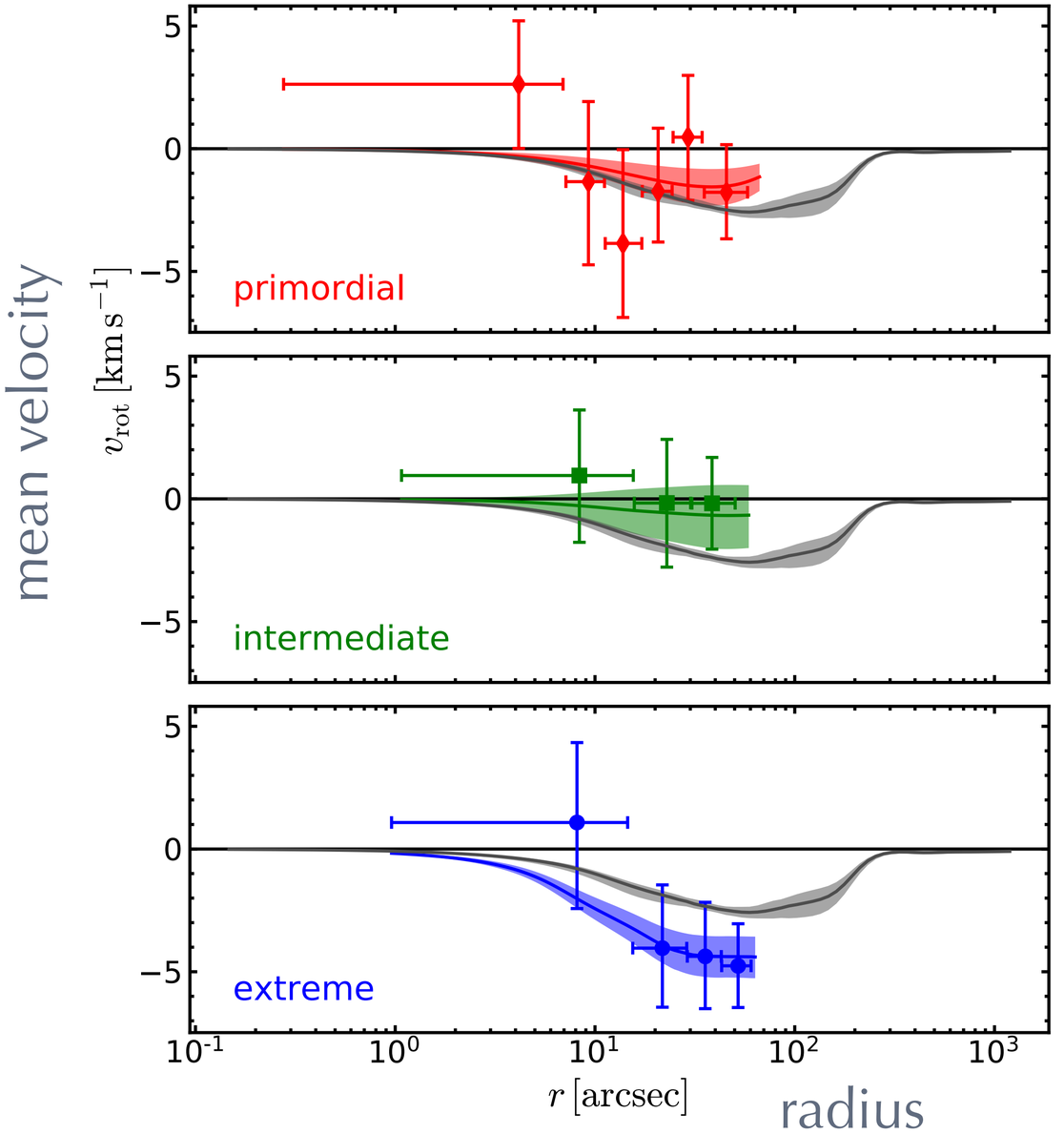
Observations + Models: Mass



Sollima+ 2016

Observations + Models: Chemo-dynamics





Kamann+ in preparation

Simulations

how clusters change over time

Simulations: Different Flavours

N-body

N particles interacting and moving under their own gravity

stellar evolution (types, luminosities, masses)

few-body interactions

Monte Carlo

Fokker-Planck

Hydrodynamic

…

Simulations: N-body

Initial conditions

Primordial binaries

Intermediate mass black hole?

Remnant retention

Environment/tidal field

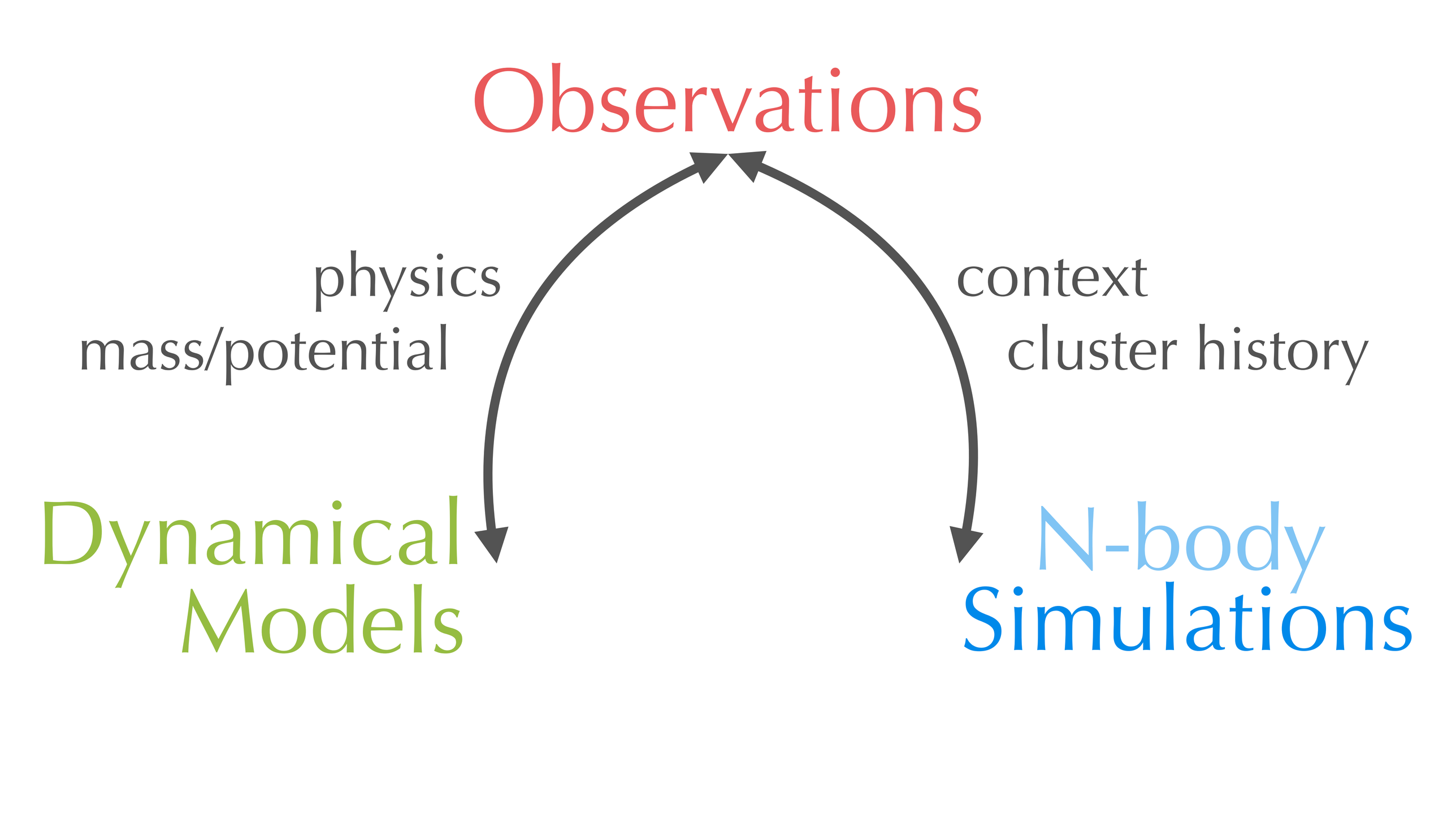
Number of particles

M4: 484 710 particles

Heggie 2014

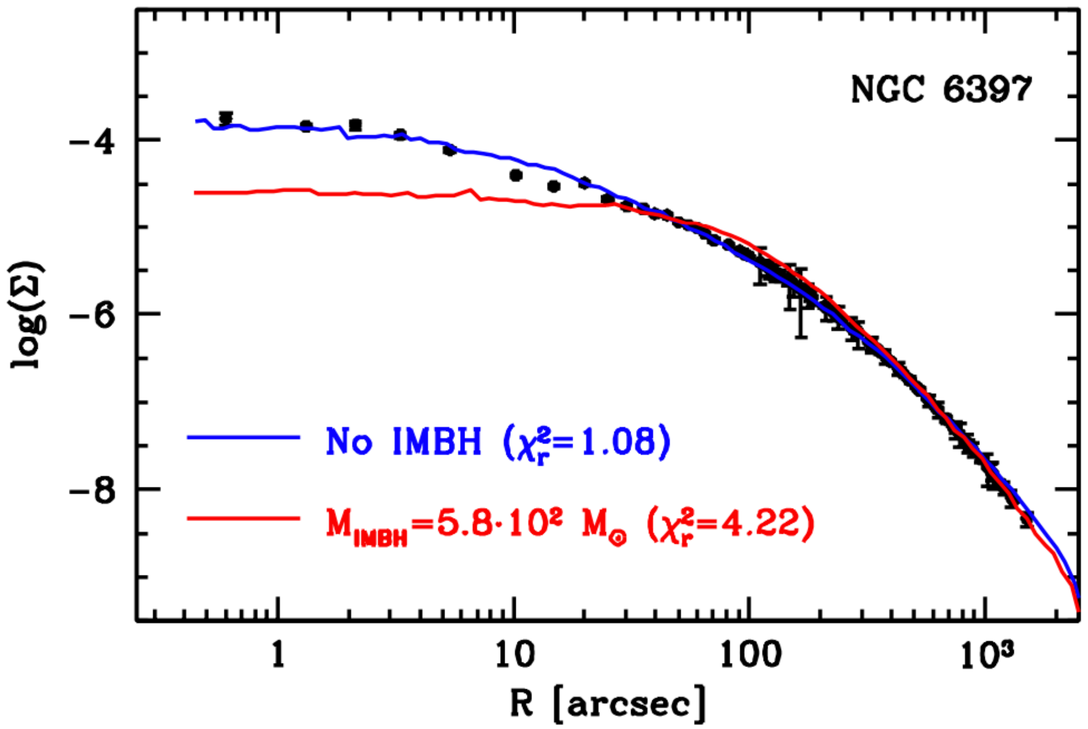
Dragon: 10^6 particles (x4)

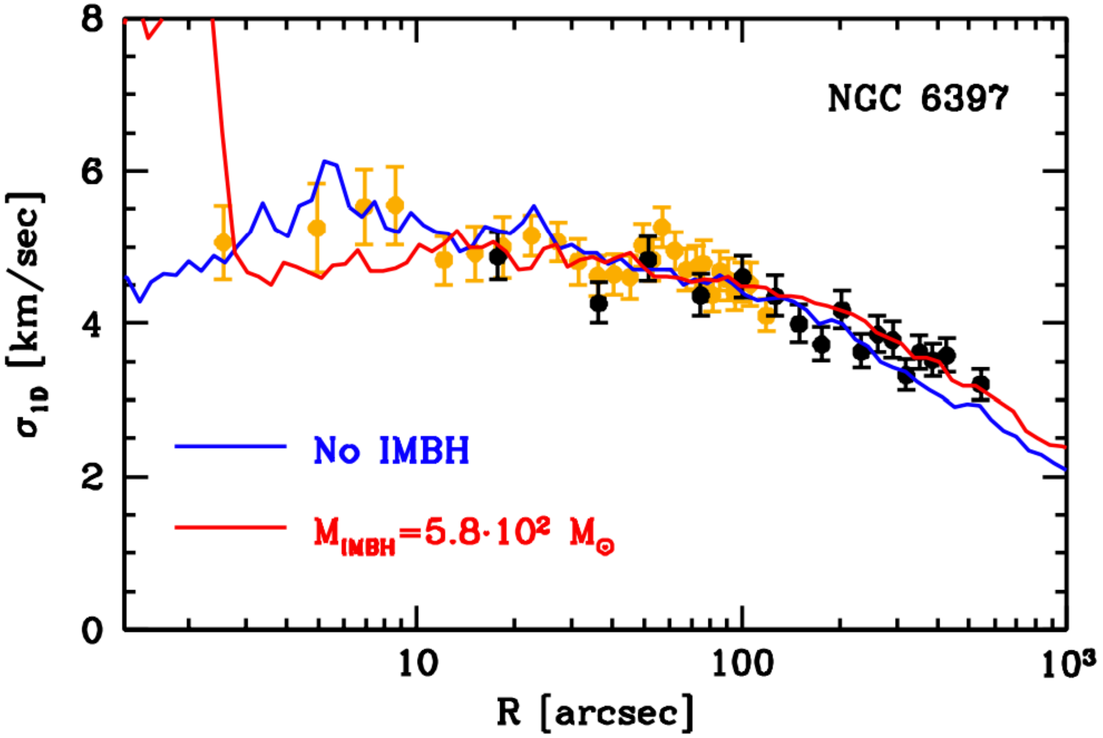
Wang+ 2016


Observations
physics
mass/potential
context
cluster history
Dynamical Models
N-body Simulations

Observations + Simulations: Mass (again)

surface density

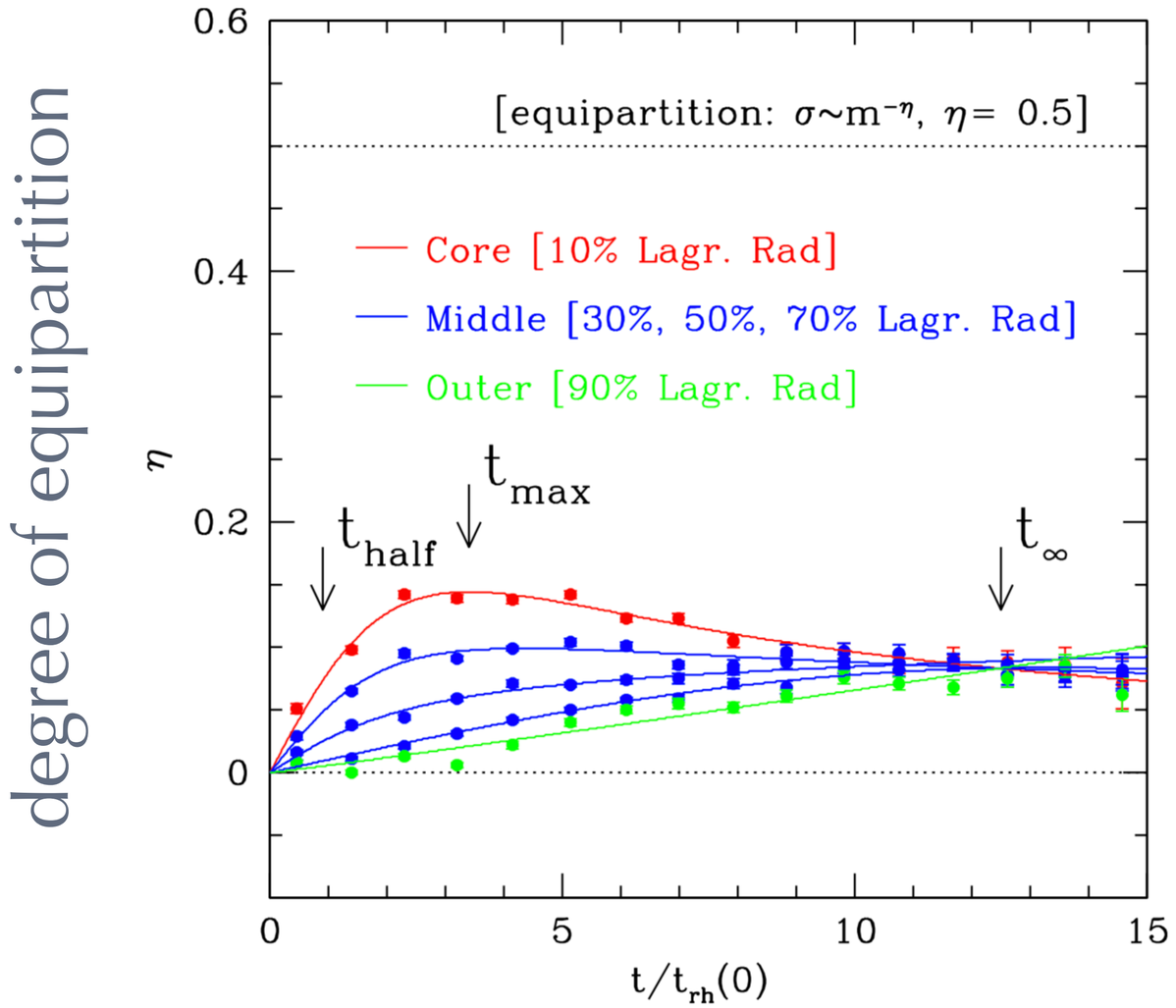




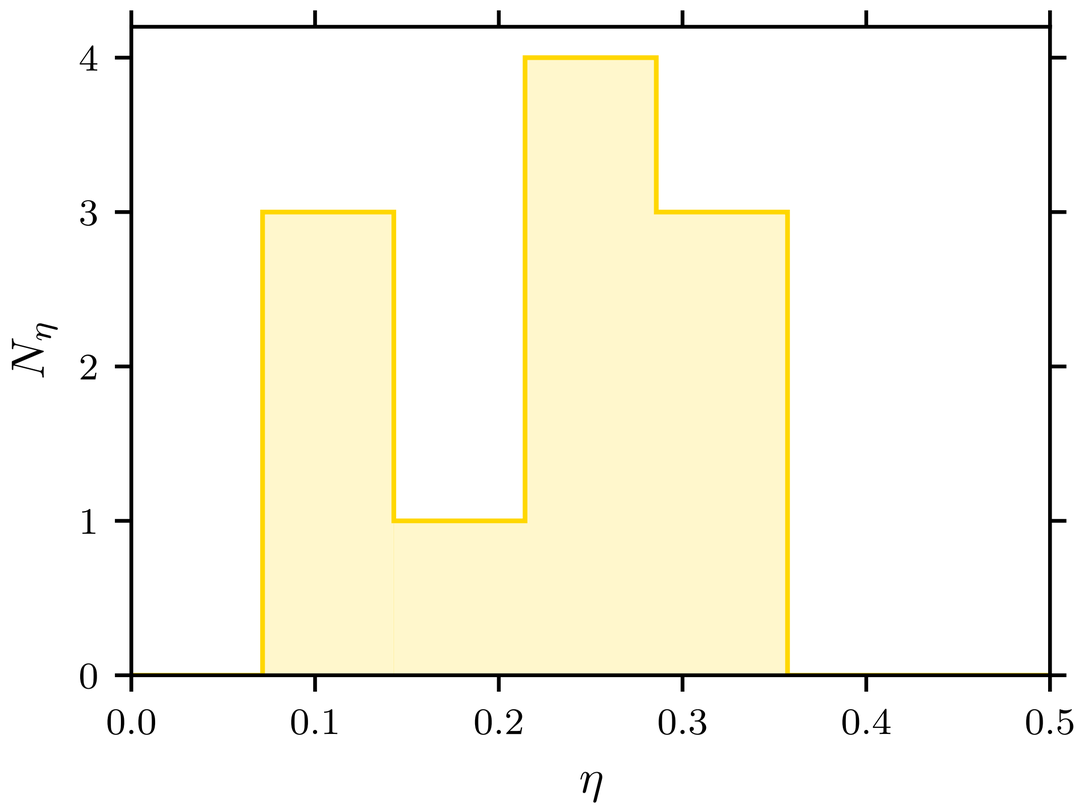
distance from cluster centre

Baumgardt+ 2017

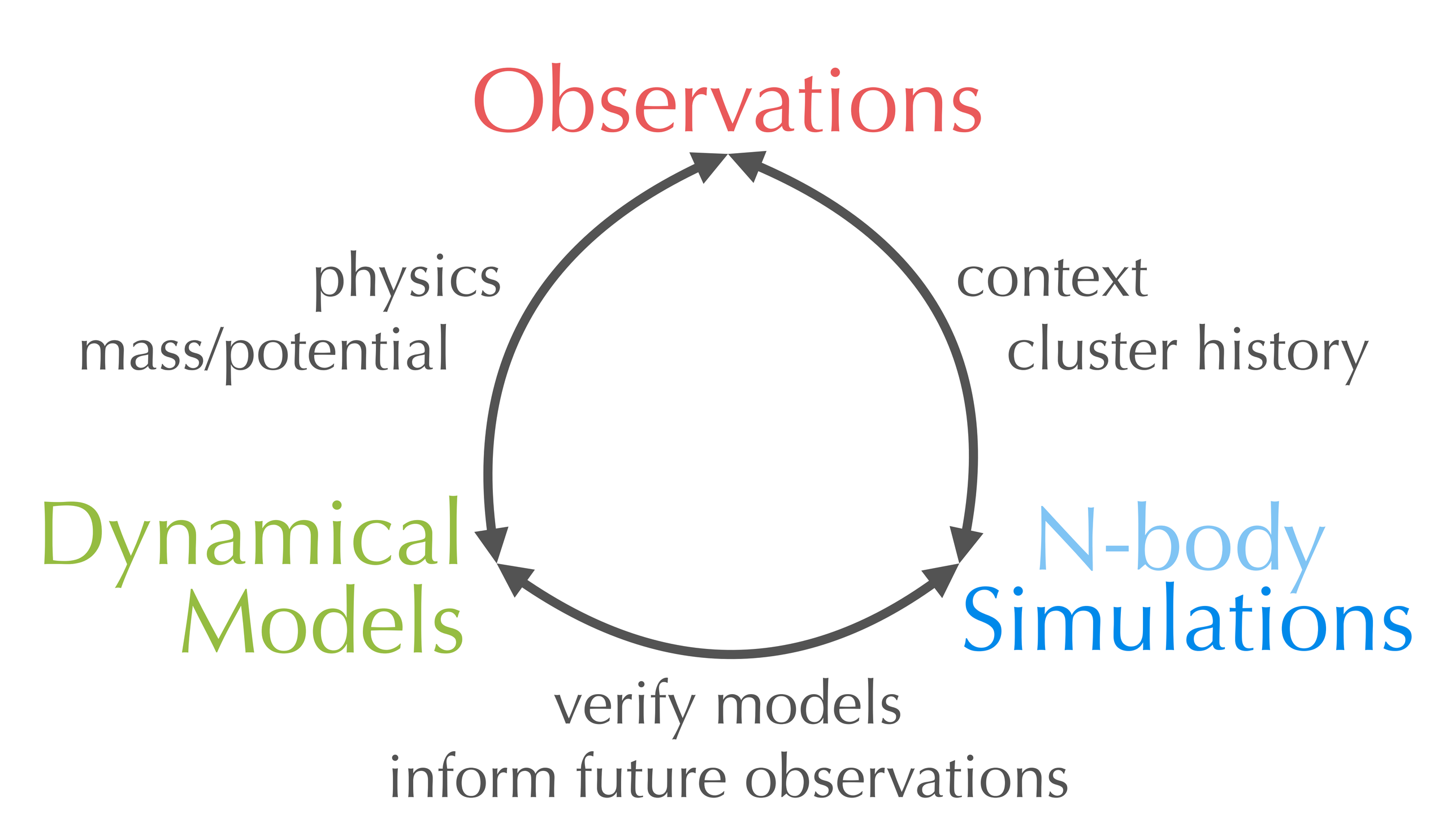
Observations + Simulations: Evolution



Trenti & van der Marel 2013



Watkins+ in preparation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cluster history
Dynamical Models
N-body Simulations
verify models
inform future observations

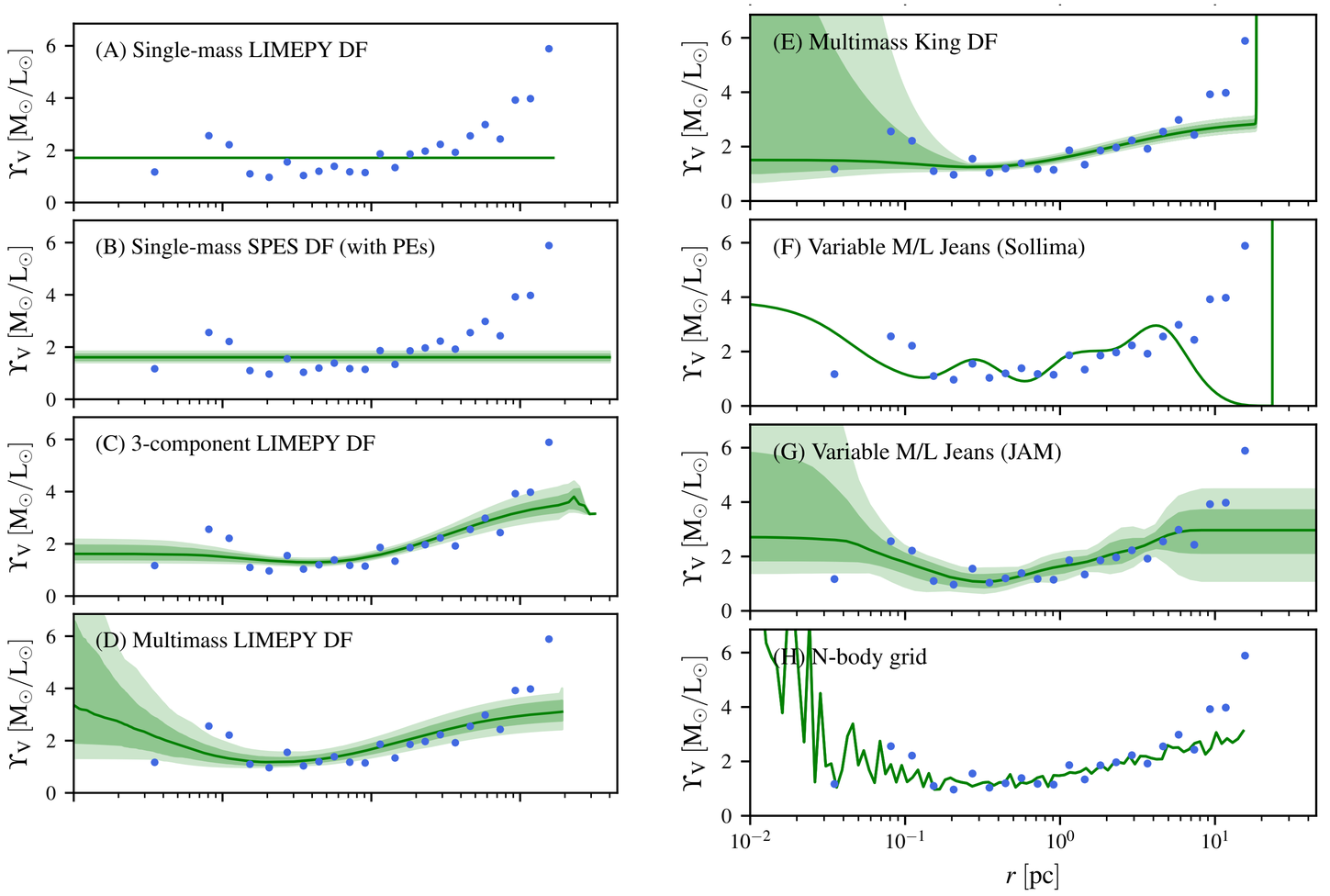
Simulations + Models: Model Comparison

N-body simulation of M4

Heggie 2014

Mock observations:

- ★ Surface brightness
- ★ LOS
- ★ HST PMs
- ★ Gaia PMs



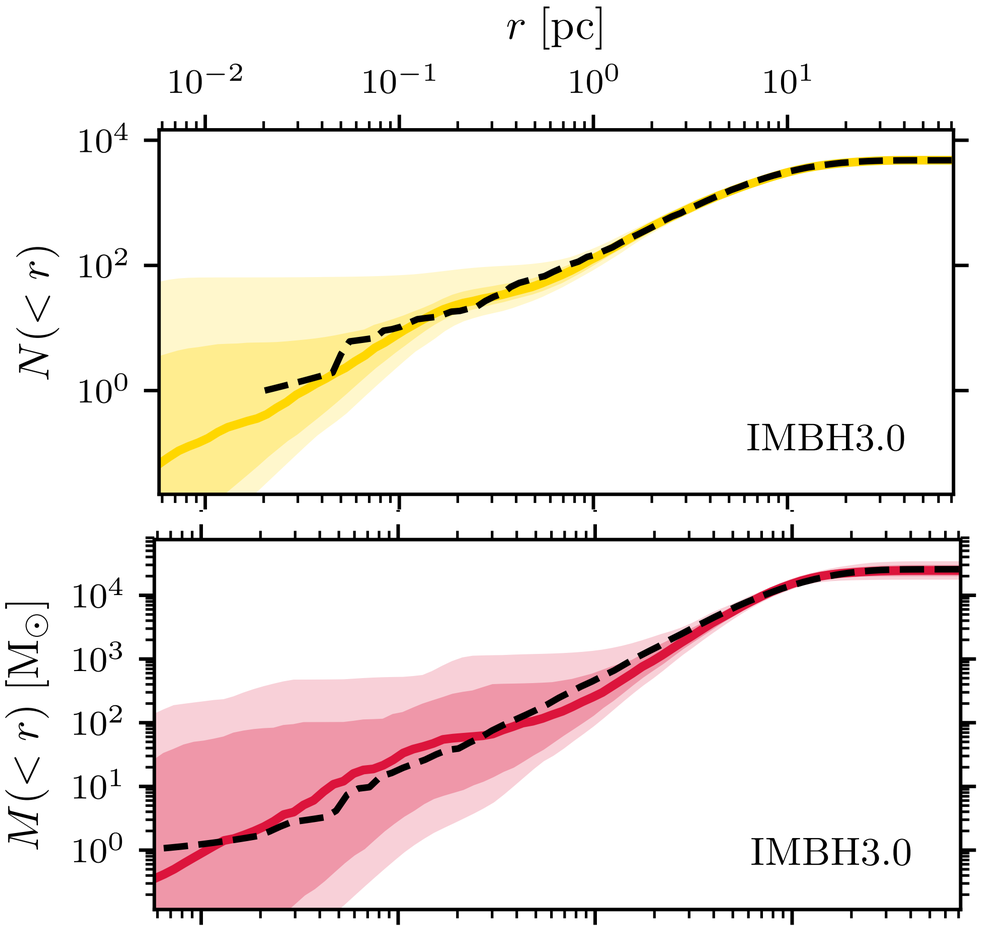
Hénault-Brunet, Gieles, Sollima, Watkins, Zocchi, Claydon, Pancino, Baumgardt 2019

Simulations + Models: Model Verification

Can we detect an IMBH?
Yes!

How?
By getting the rest of the cluster right.

Can mass-segregated remnants mimic an IMBH?
No.



Watkins+ in preparation

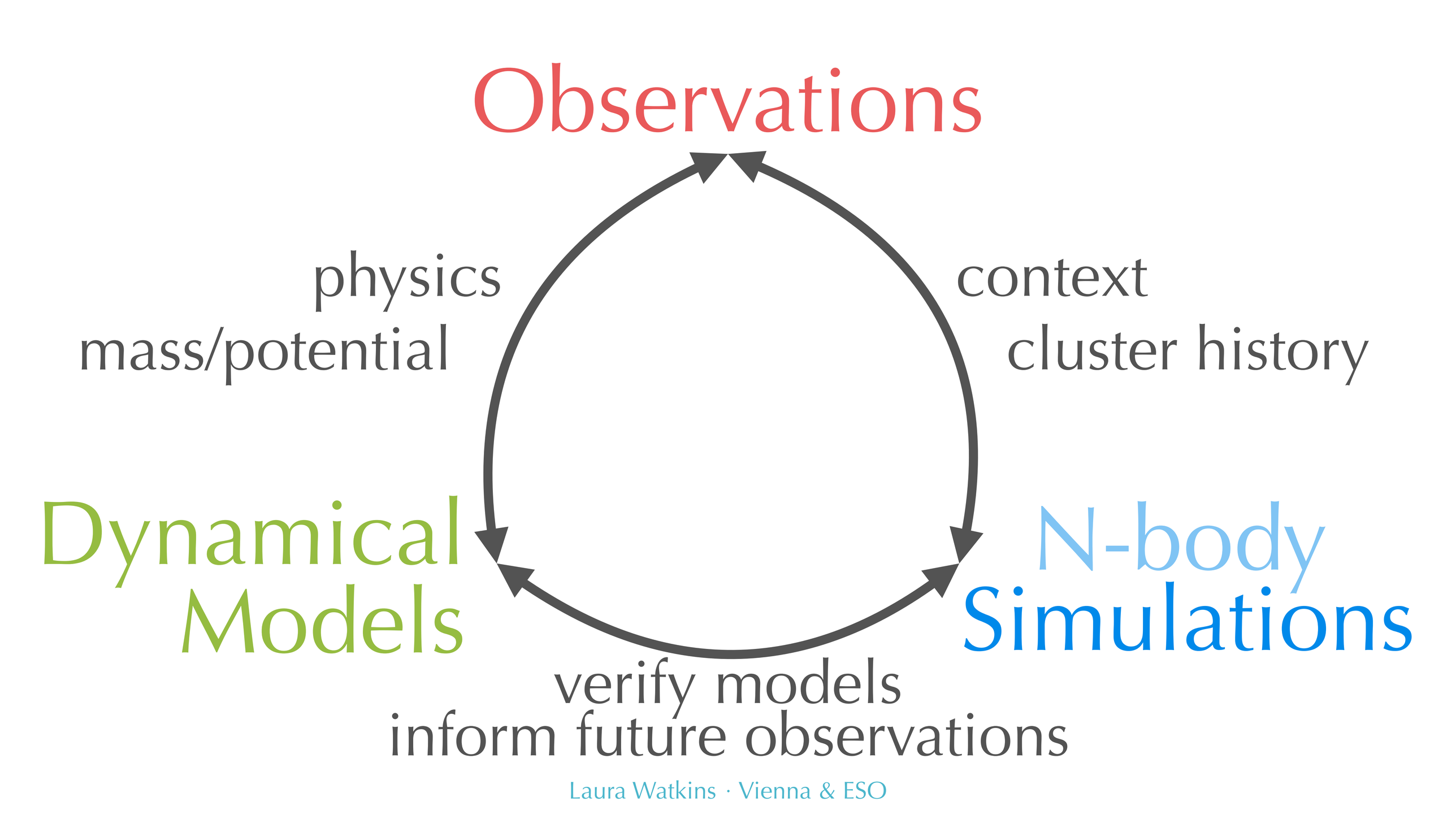
Simulations + Models: Inform observations

What data do we need?

Optimise sample size or uncertainties?

Stay tuned!

Watkins+ in preparation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