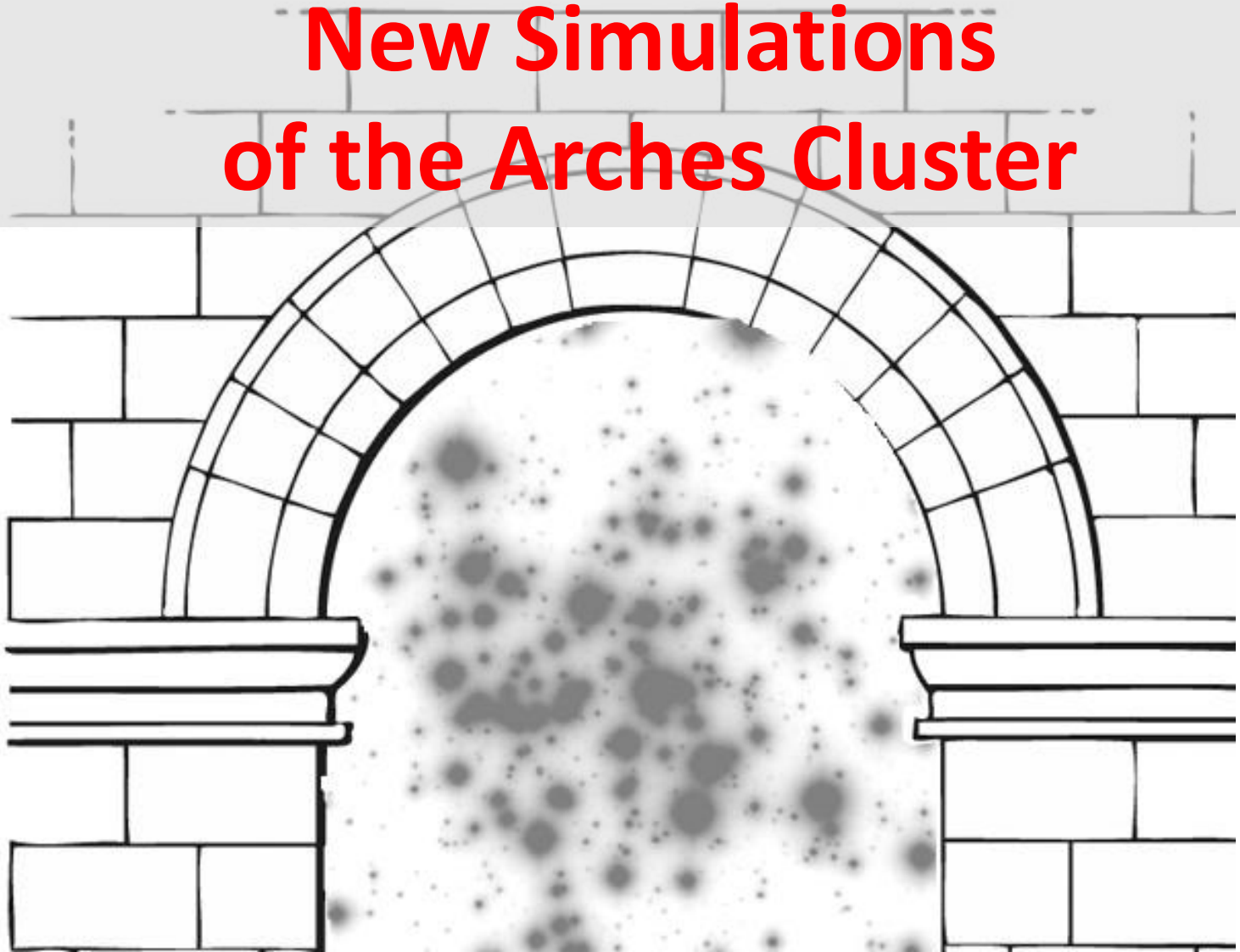
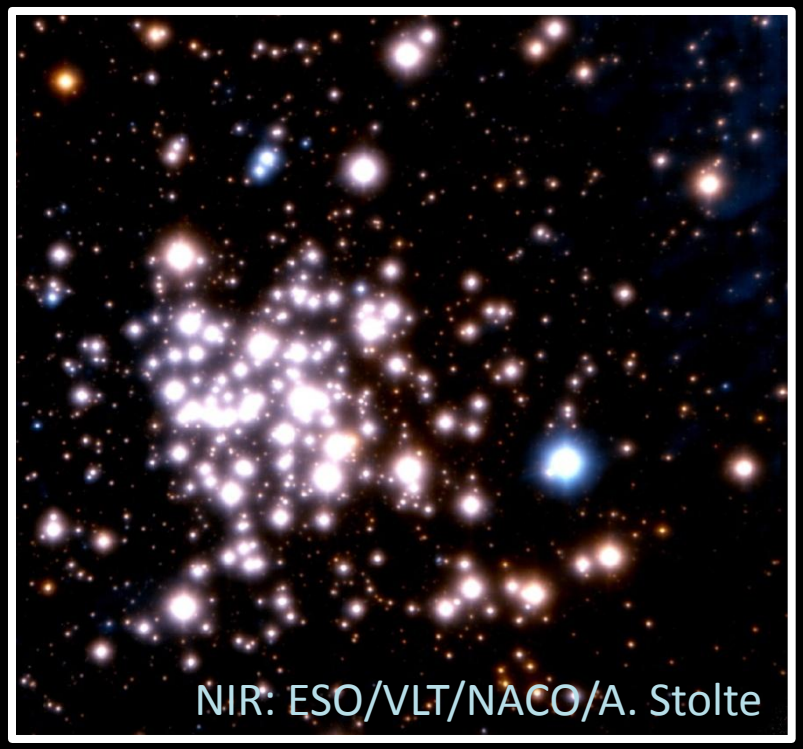
Stefan Harfst
Center for Astronomy and Astrophysics, TU Berlin
with Simon Portegies Zwart (Leiden) and Andrea Stolte (Bonn)

New Simulations of the Arches Cluster



The Arches Cluster

Credits: Radio: NRAO/AUI/NSF/C.Lang
NIR: ESO/VLT/NACO/A. Stolte



The Arches Cluster

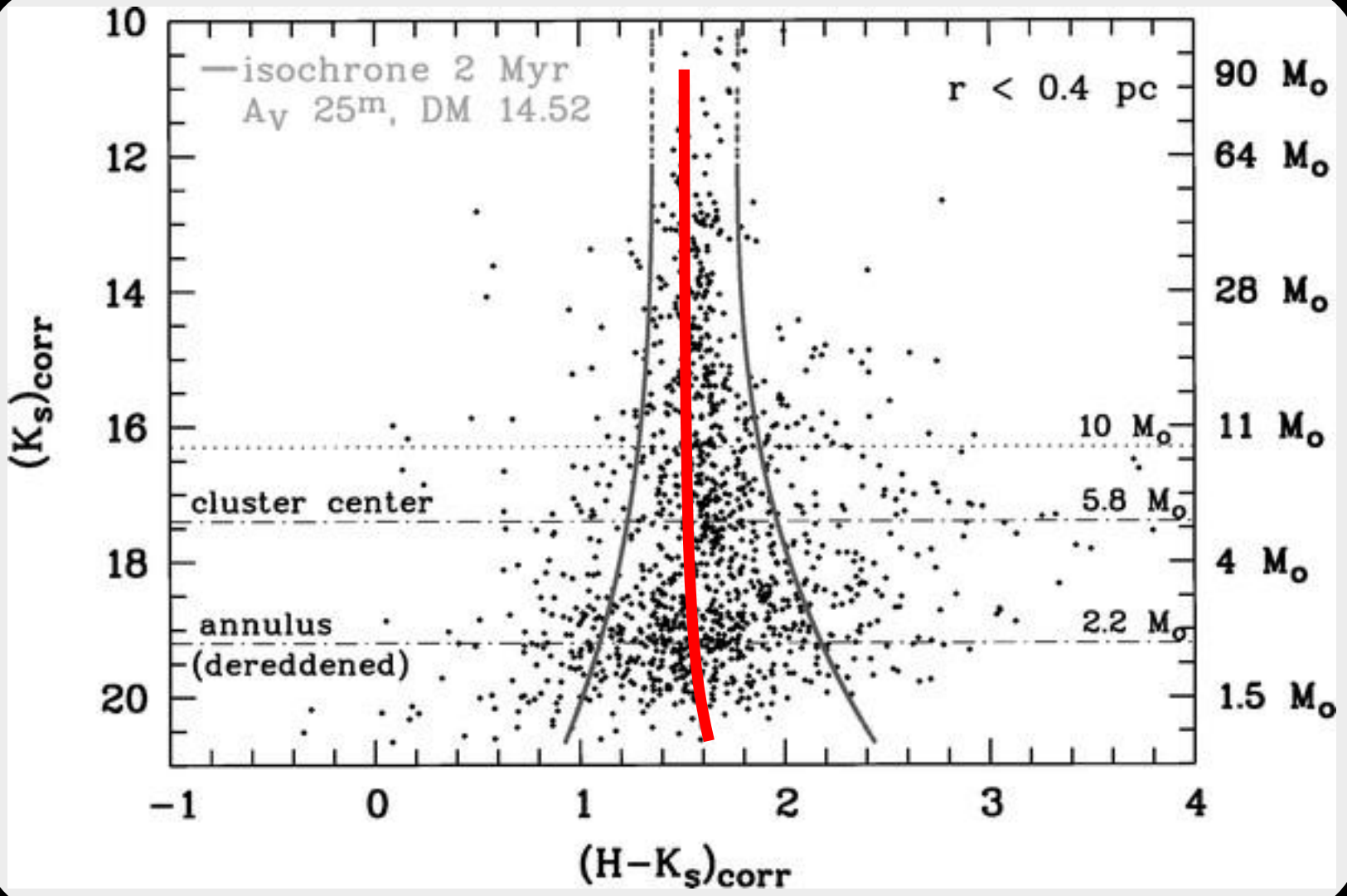
- densest cluster in the MW
  - >100 O-Stars within 1pc
- only ~2.5Myr old
- one of only a few star burst clusters in the MW
- nearby the Galactic center
  - projected distance ~30pc

The Arches cluster is a unique object to study star formation and the dynamical evolution of dense stellar systems in a strong tidal field !

Motivation: what can we learn from N-body models about the past and the future of the Arches cluster

Observations of the Arches Cluster

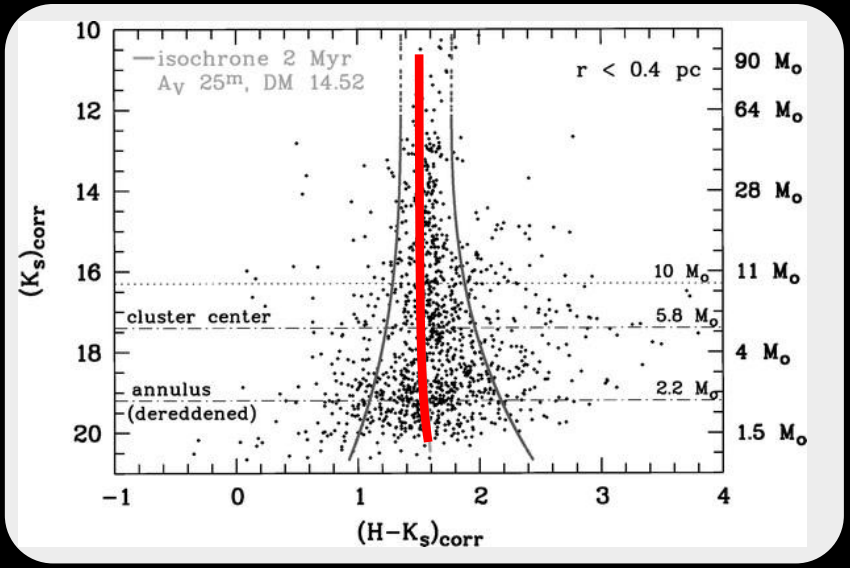
Cluster Membership



(Stolte et al., 2005)

Observational Data

(Stolte et al., 2005)

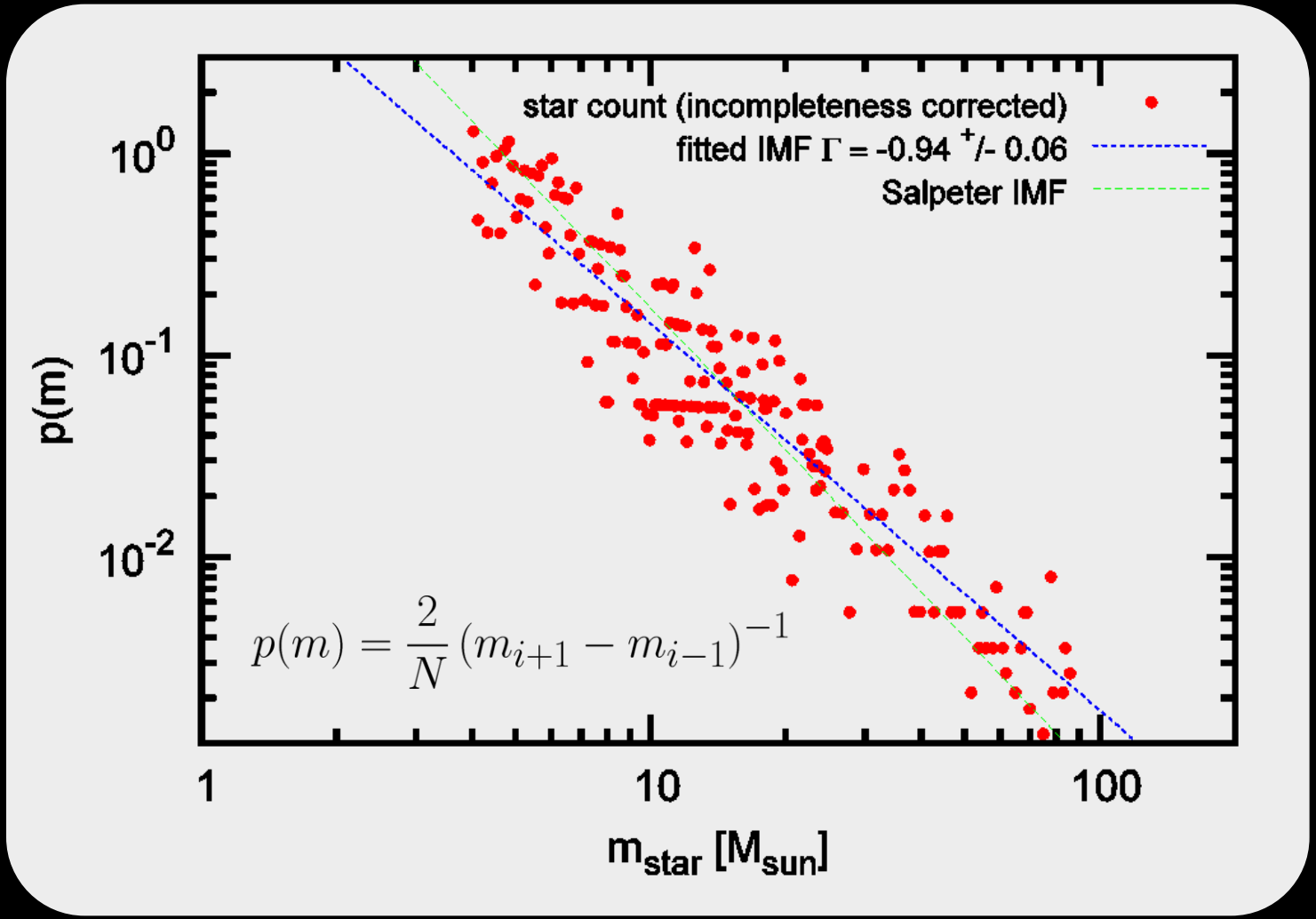


- data from VLT/NACO
  - AO NIR photometry
  - two wave-bands (H and K)
- cluster membership by color selection
  - approximately 1500 stars
- stellar masses from Geneva tracks (Lejeune & Schaerer, 2001)
  - assumed age 2.5Myr
  - solar metallicity

Our Observational Sample

- cluster membership by H-K-color selection
  - approximately 1500 stars
- lower mass limit of $10M_{\odot}$
  - completeness fraction >75%
  - leaves 300 stars
- maximum radius of 0.4pc
  - completely covered by FOV
  - total number of stars in sample 234

Arches Initial Mass Function

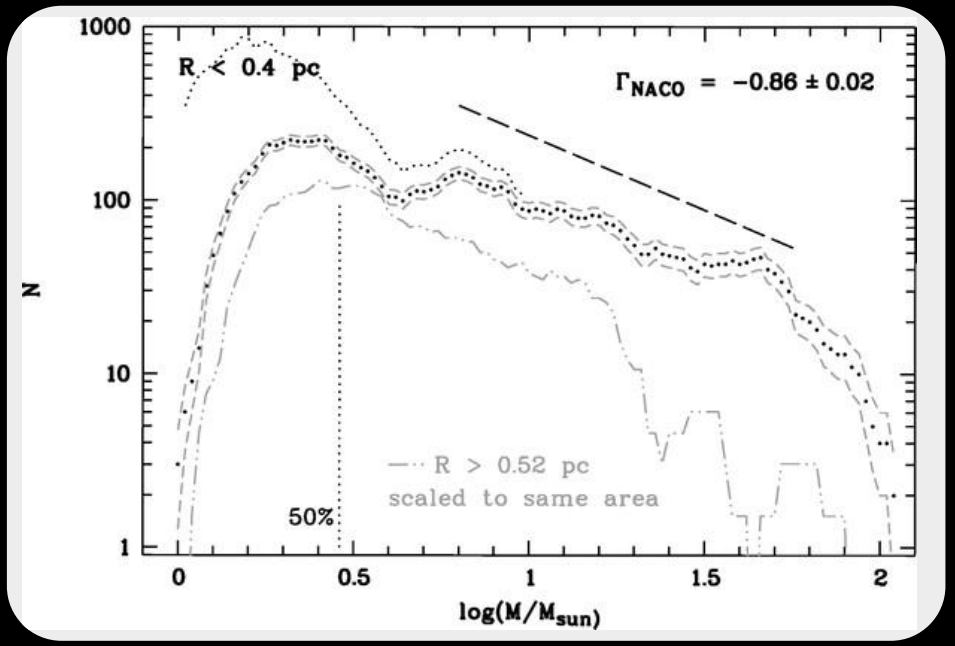


(Harfst, Portegies Zwart, & Stolte, 2010, MNRAS, 409, 628)

Arches Initial Mass Function

(Stolte et al., 2005)

- Is the IMF of Arches standard?
  - has formed in extreme environment
  - observed MF shallower than Salpeter

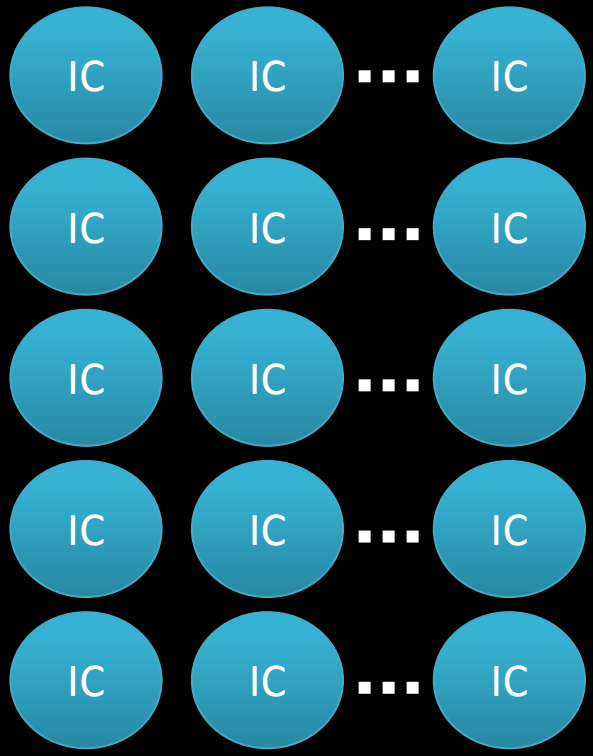


- is the observed MF also the IMF?
  - dynamical effects are not taken into account

First Simulations

Constraining Initial Conditions

Fitting a Model to Observations



Initial Conditions (ICs):
mass, IMF, concentration, age, orbit, …

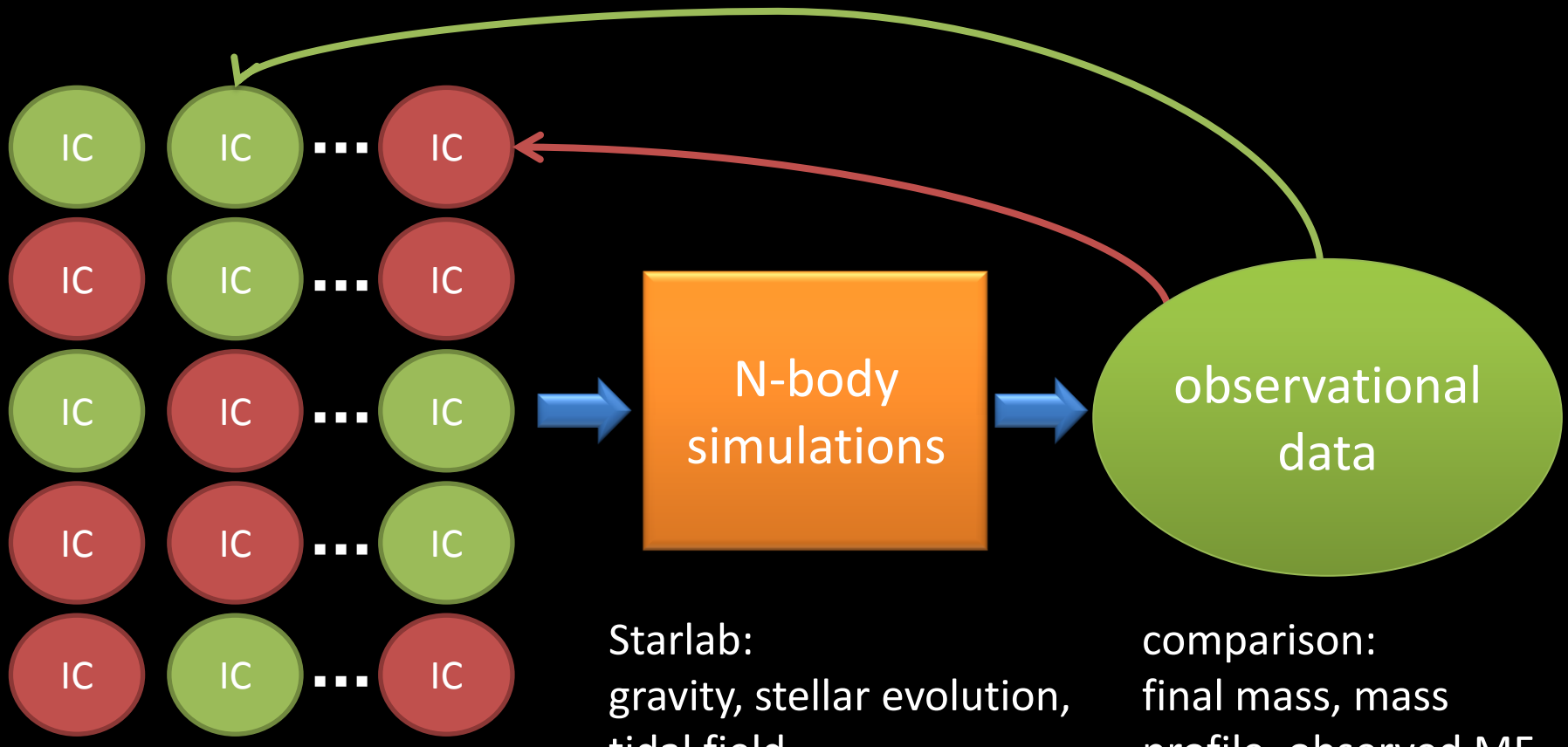
N-body simulations

Starlab:
gravity, stellar evolution, tidal field

observational data

comparison:
final mass, mass profile, observed MF

Fitting a Model to Observations

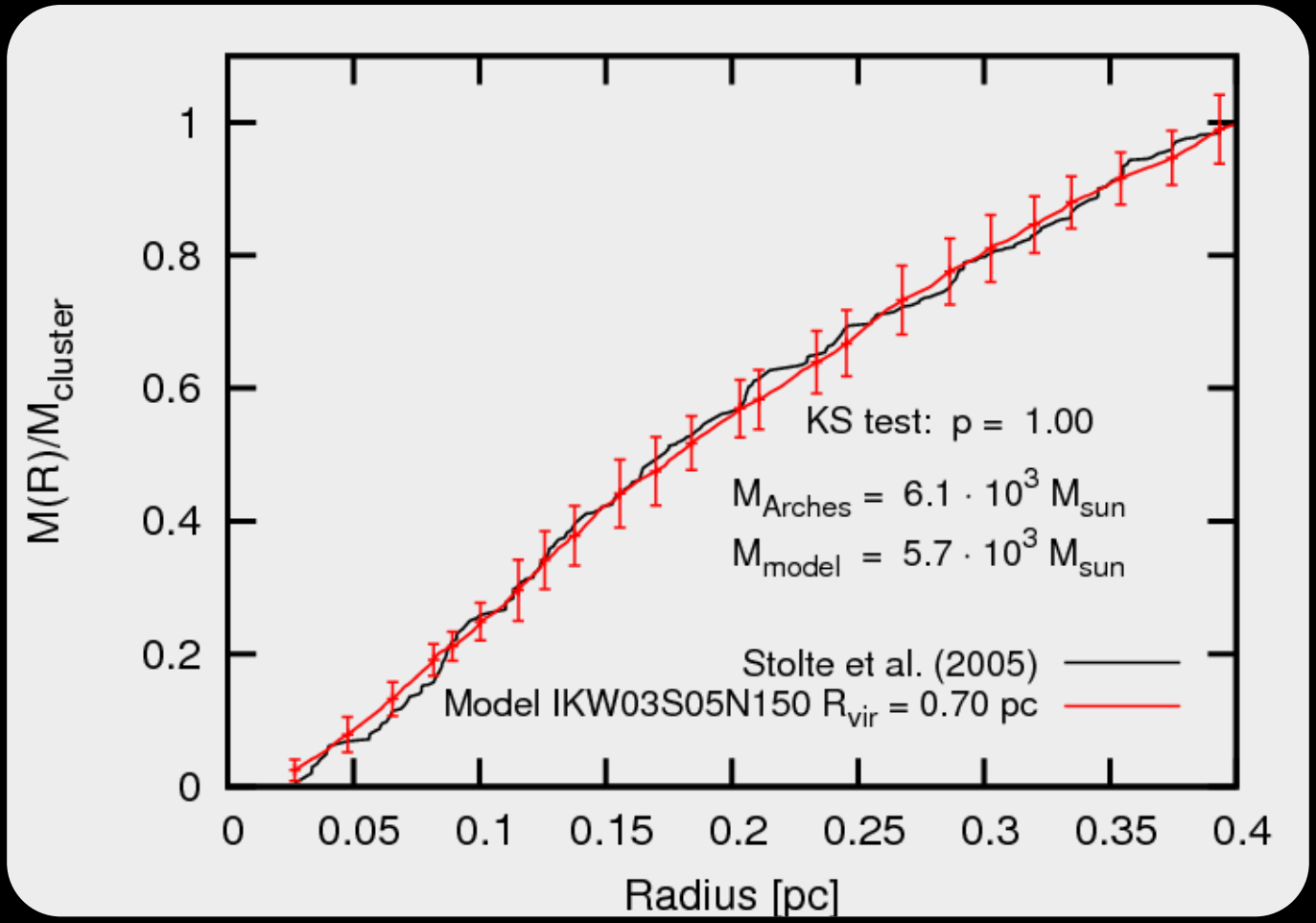


Initial Conditions (ICs):
mass, IMF, concentration, age, orbit, …

Starlab:
gravity, stellar evolution, tidal field

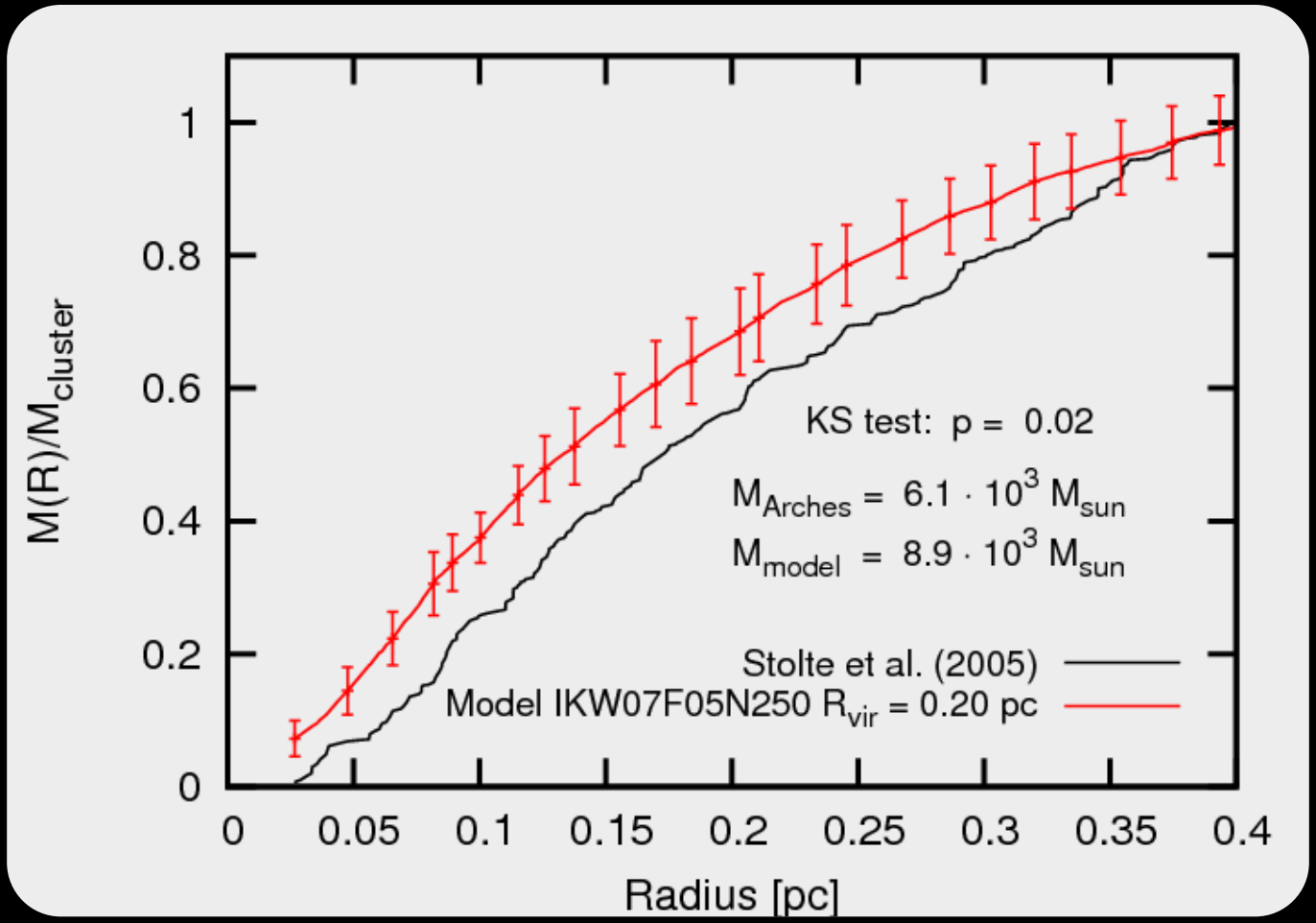
comparison:
final mass, mass profile, observed MF

Comparing Cumulative Mass Profile



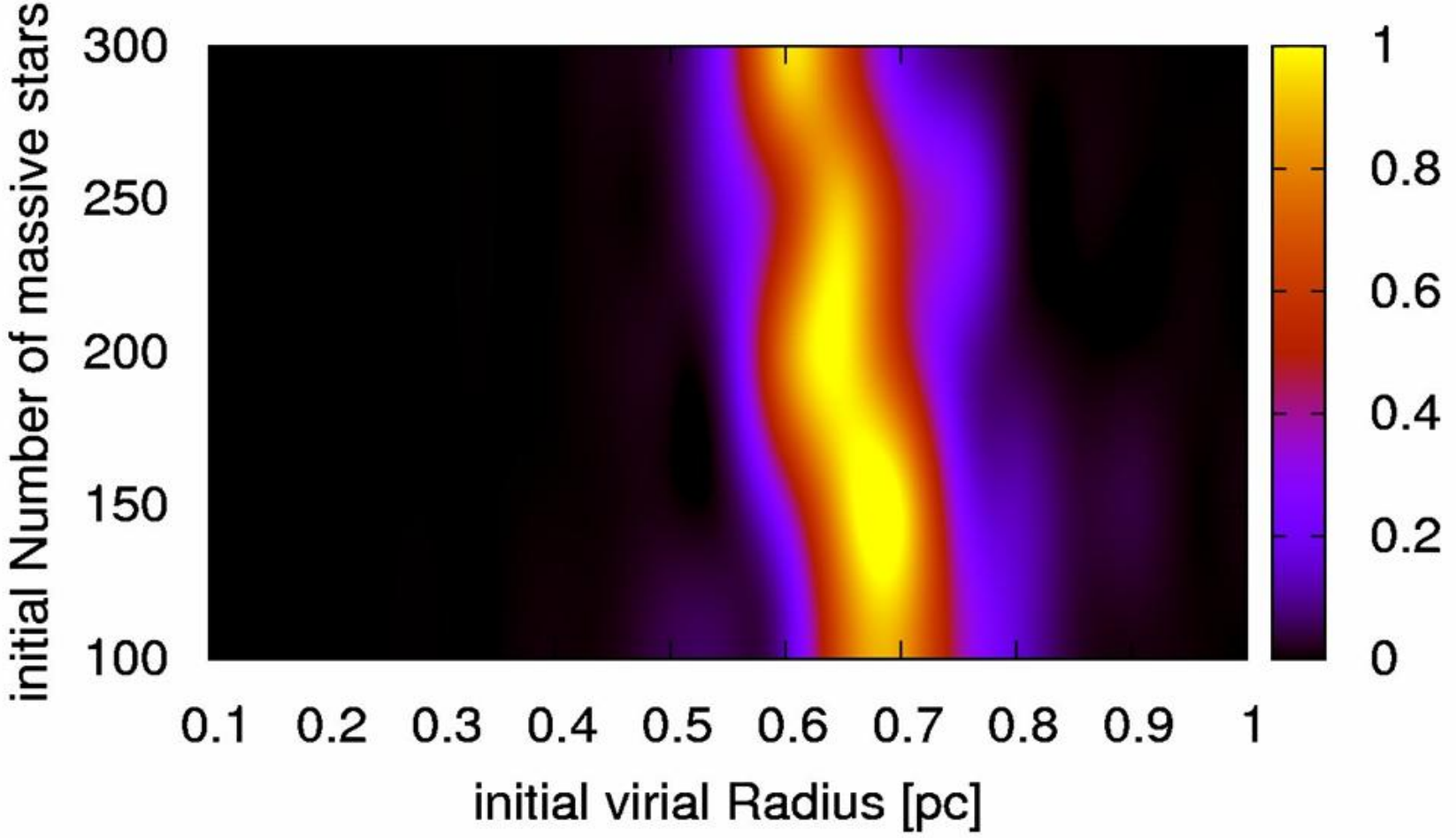
(Harfst, Portegies Zwart, & Stolte, 2010, MNRAS, 409, 628)

Comparing Cumulative Mass Profile



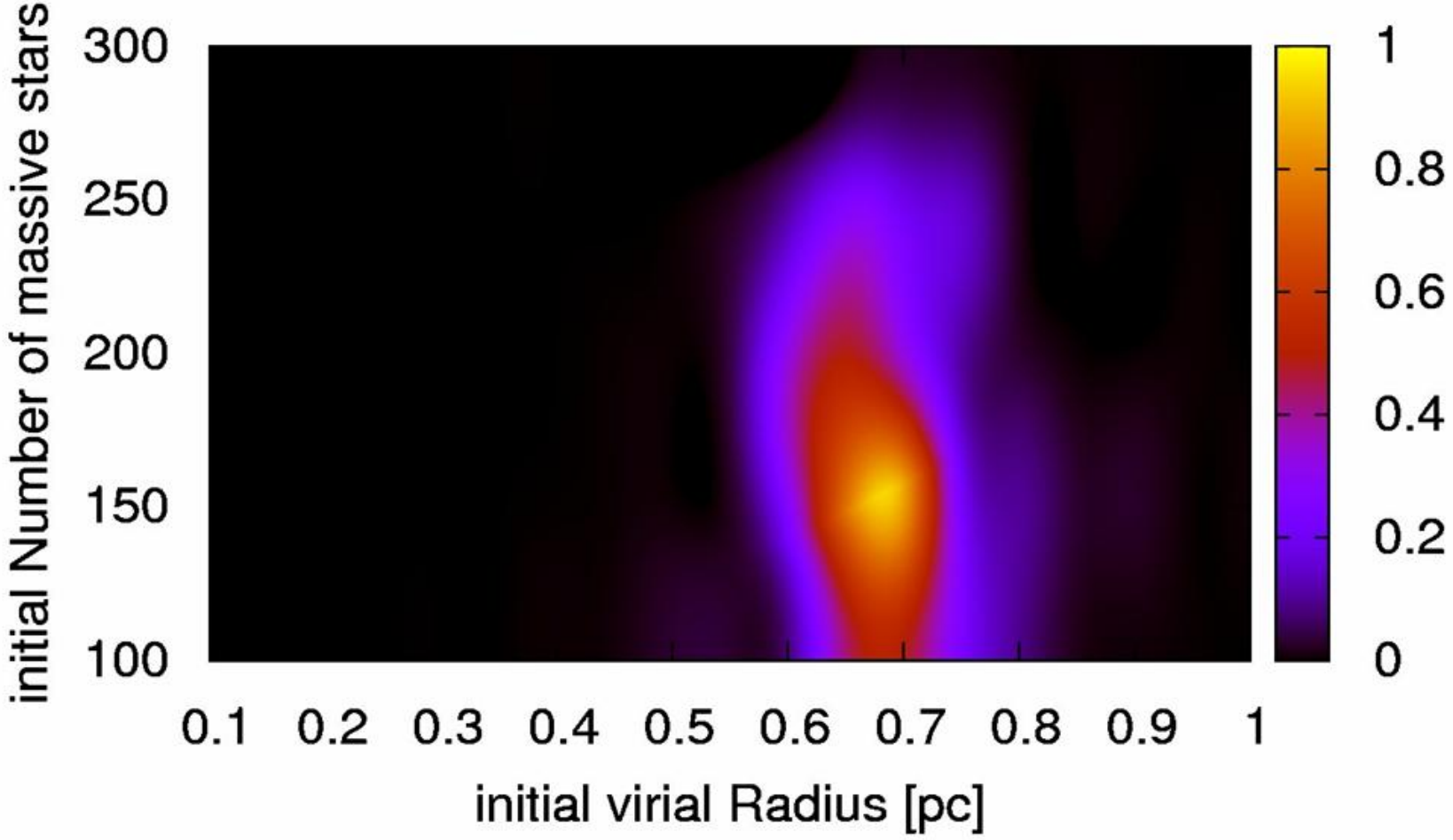
(Harfst, Portegies Zwart, & Stolte, 2010, MNRAS, 409, 628)

Comparing Cumulative Mass Profile



(Harfst, Portegies Zwart, & Stolte, 2010, MNRAS, 409, 628)

Comparing Everything



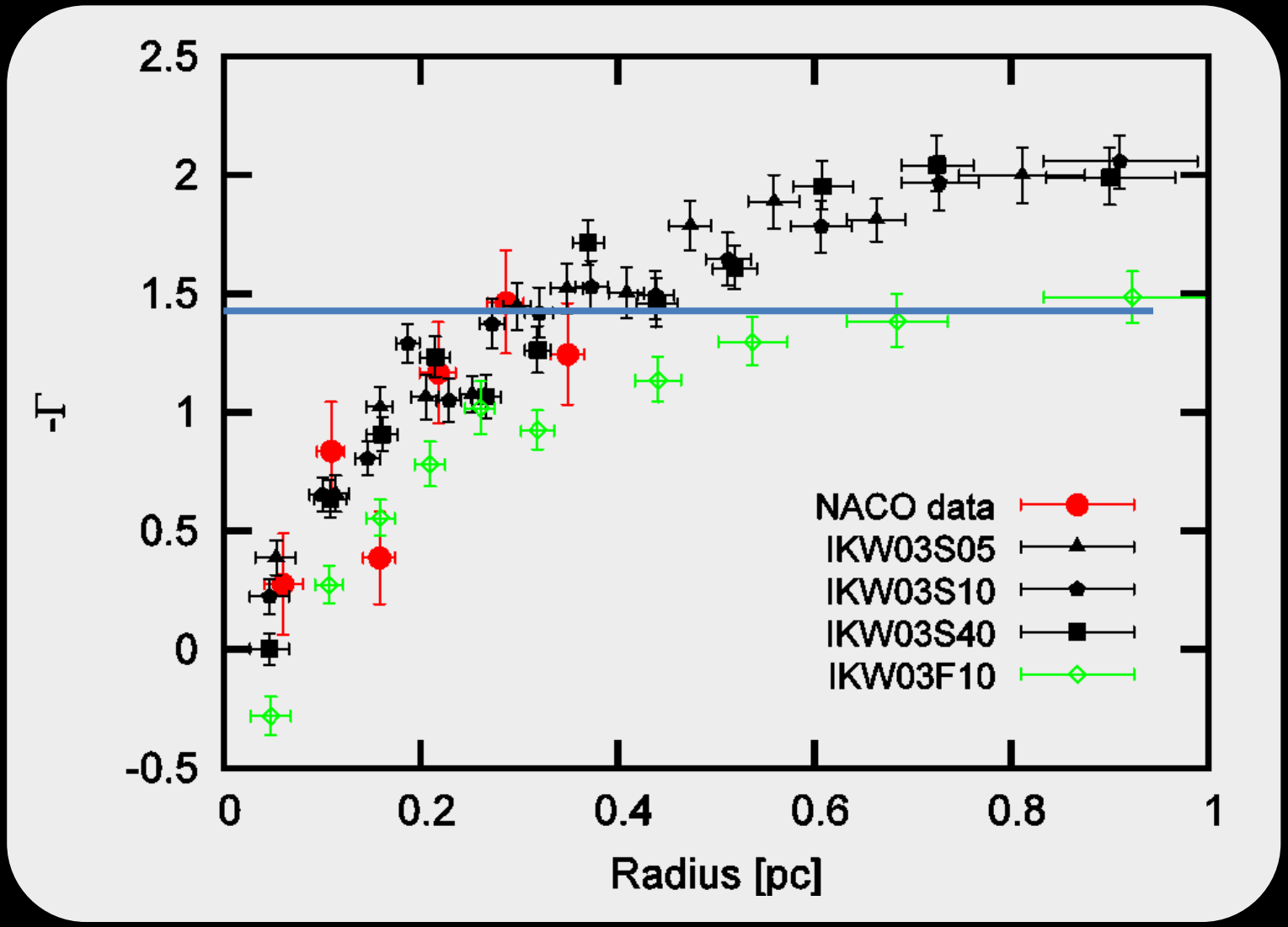
(Harfst, Portegies Zwart, & Stolte, 2010, MNRAS, 409, 628)

Results – Best Fit Model

- found best fit model with
  - Salpeter IMF
  - virial radius 0.7pc
  - total initial mass $4x10^4 M_\odot$
  - lower mass limit IMF $0.5 M_\odot$
  - initial concentration $W_0=3$

Model	Parameters		f_{all}
	N_{MS}	r_{vir}	
IKW03F05	200	0.65	0.333389
IKW03F10	200	0.70	0.389688
IKW03S05	150	0.70	0.928229
IKW03S10	150	0.65	0.891674
IKW03S40	200	0.60	0.72182
IKW05F05	200	0.85	0.411755
IKW05F10	250	0.90	0.427615
IKW05S10	200	0.80	0.791796
IKW05S40	200	0.75	0.872719
IKW07F05	200	0.75	0.468826
IKW07F10	250	0.85	0.554017
IKW07S10	200	1.00	0.751365
IKW07S40	200	0.70	0.861753

Radial MF variations



(Harfst, Portegies Zwart, & Stolte, 2010, MNRAS, 409, 628)

New Simulations

Including Orbit and Stellar Evolution

(sorry, still no primordial binaries)

Why New Simulations?

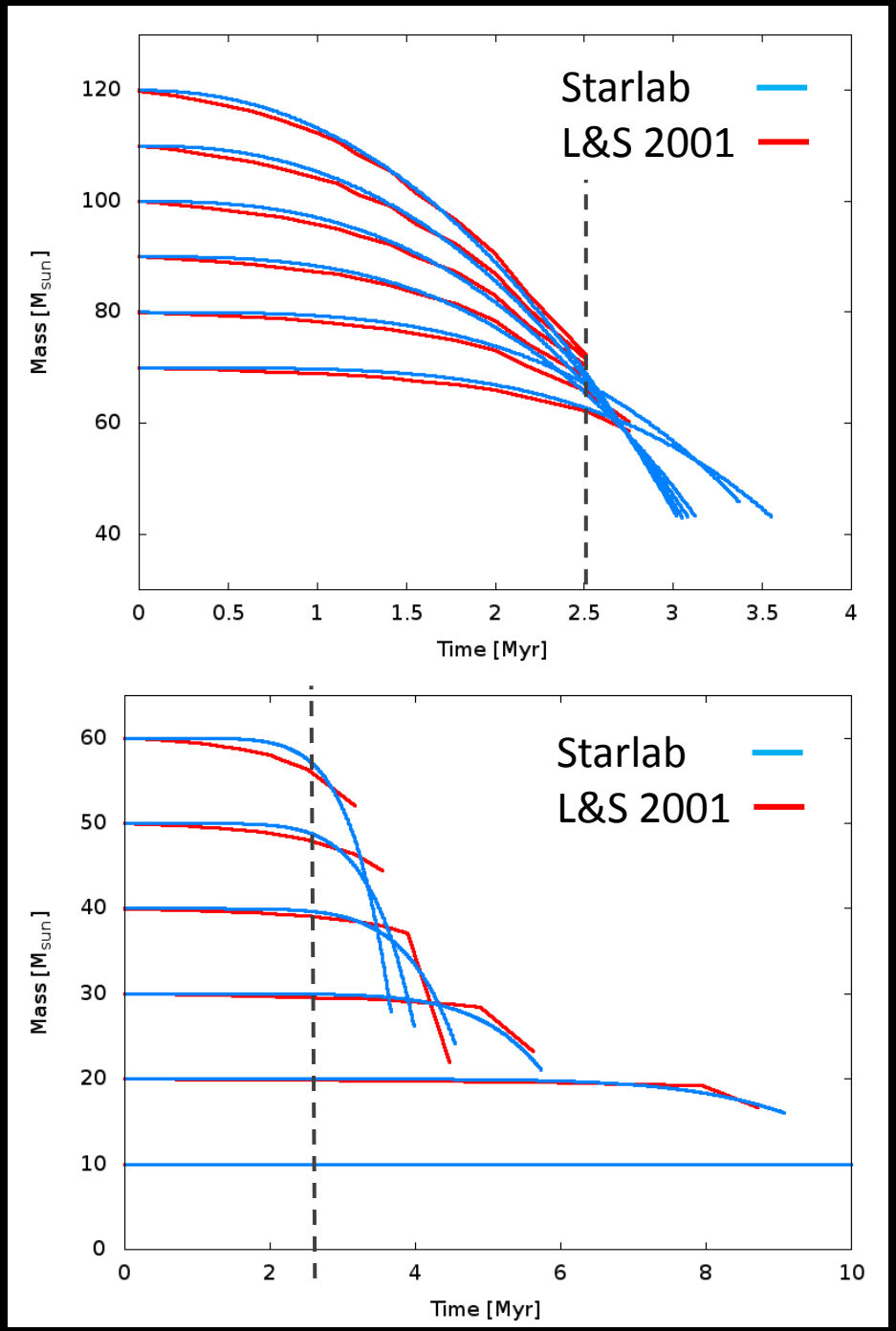
- how well is the Arches cluster described by the fitted scale-free models?

assumption 1: stellar evolution has little influence since the cluster is very young

assumption 2: the tidal field can be ignored

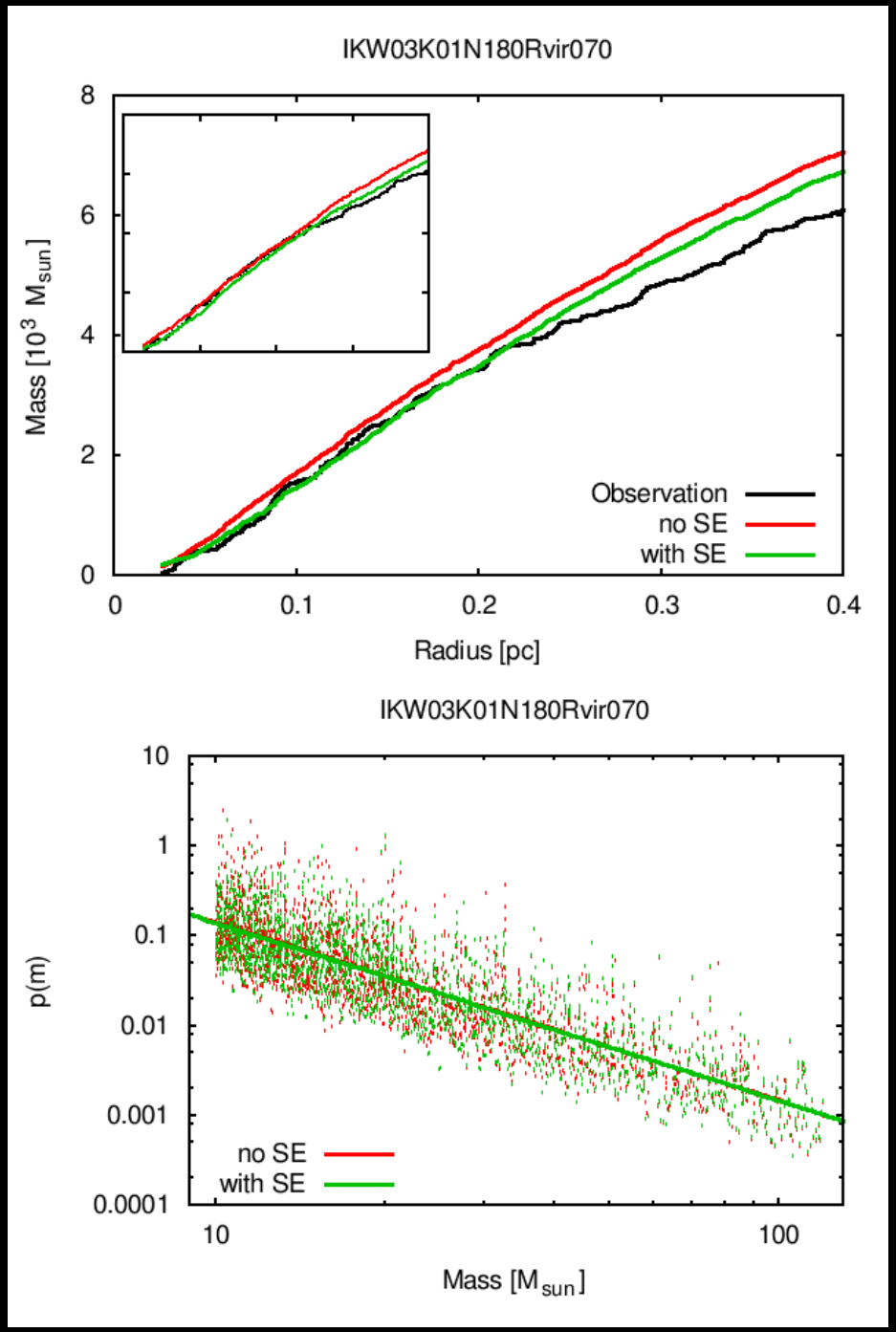
Influence of Stellar Evolution

- stellar mass-loss is taken into account
- important in Arches for the most massive stars
- adapted Starlab to the mass-loss from Lejeune & Schaerer (2001)



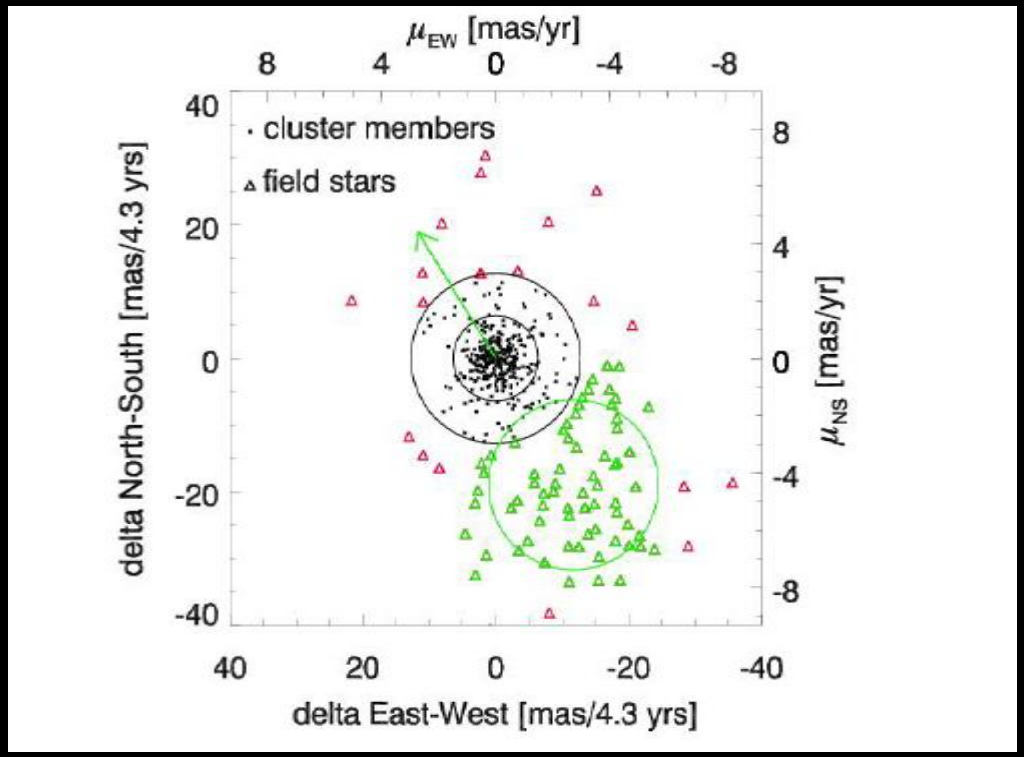
Influence of Stellar Evolution

- mass-loss only has a small effect on cluster evolution
  - difference in mass-profiles is within 1σ-error bars
  - slope of observed mass functions are very similar
- changing lower mass-limit of the IMF to $1M_{sun}$
  - mass profiles show small difference
  - MF slopes are a little shallower

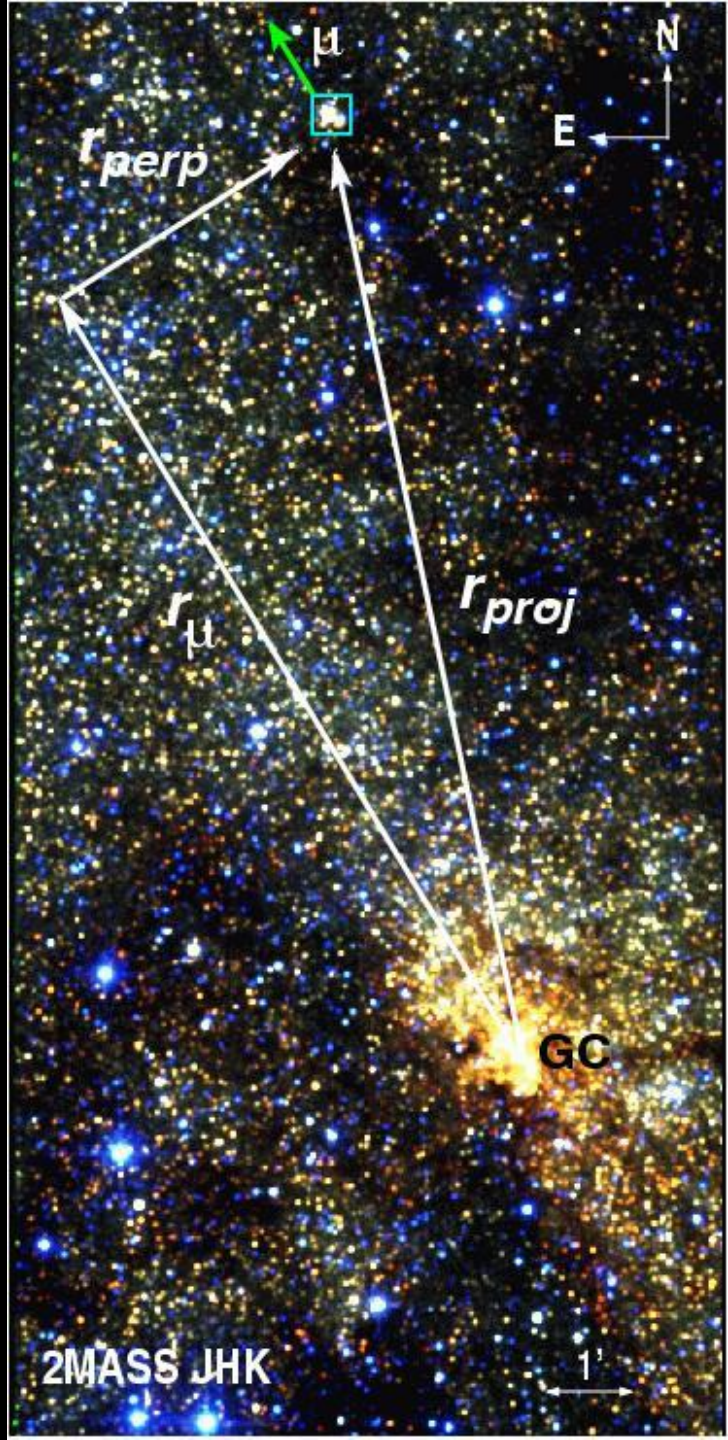


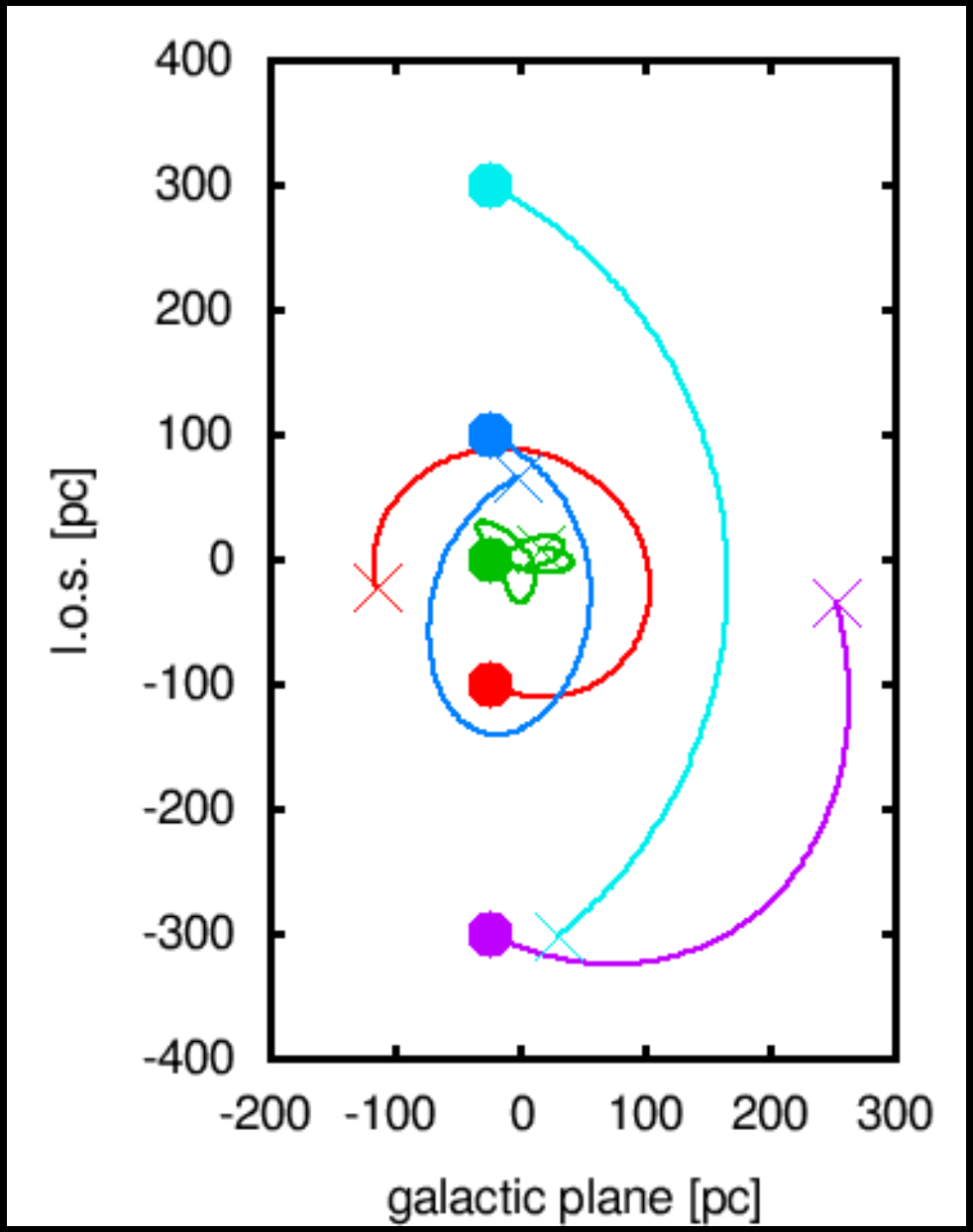
Cluster orbit

- known proper motion of the cluster
  - line-of-sight distance can be varied



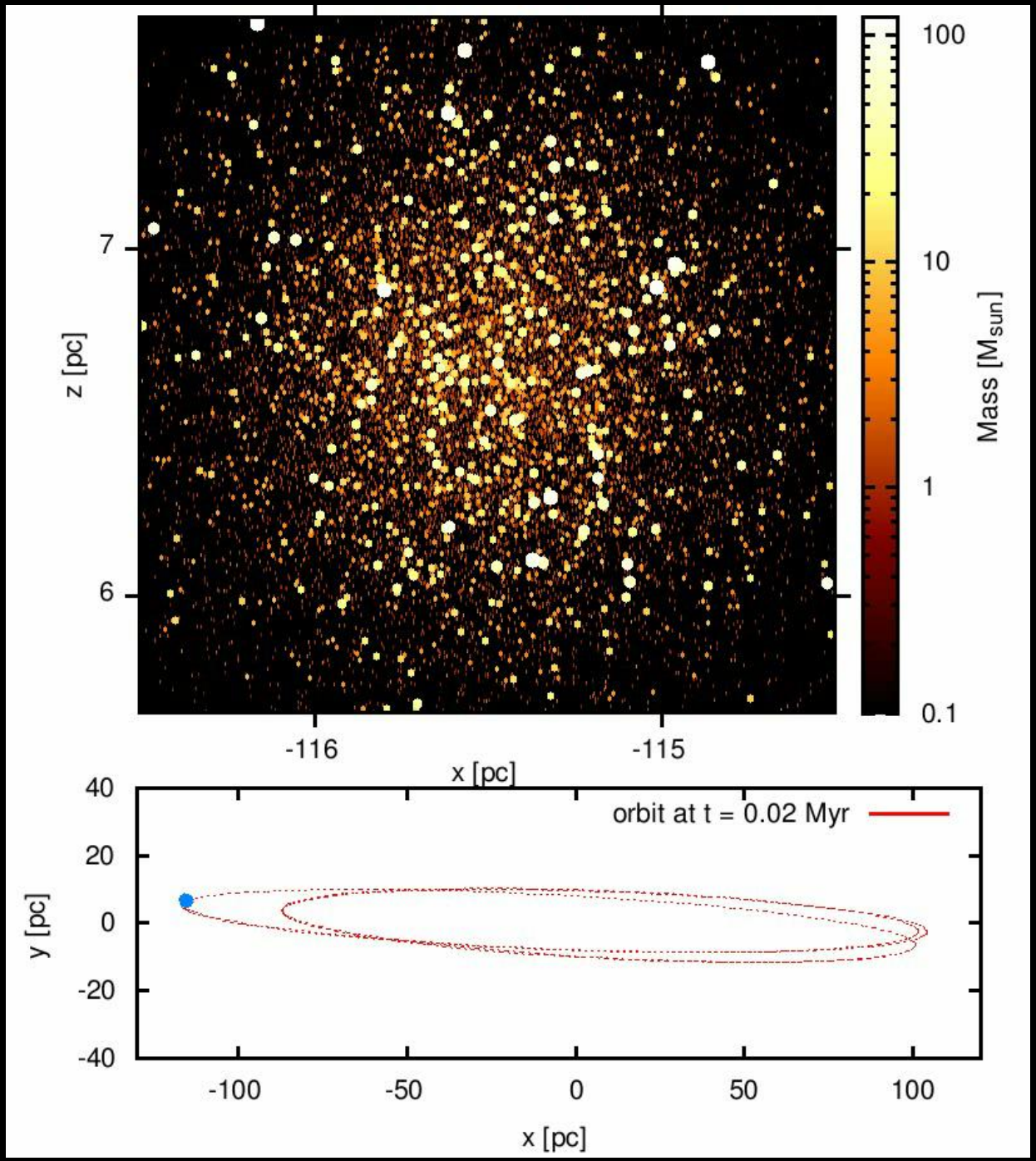
(Stolte et al., 2008)

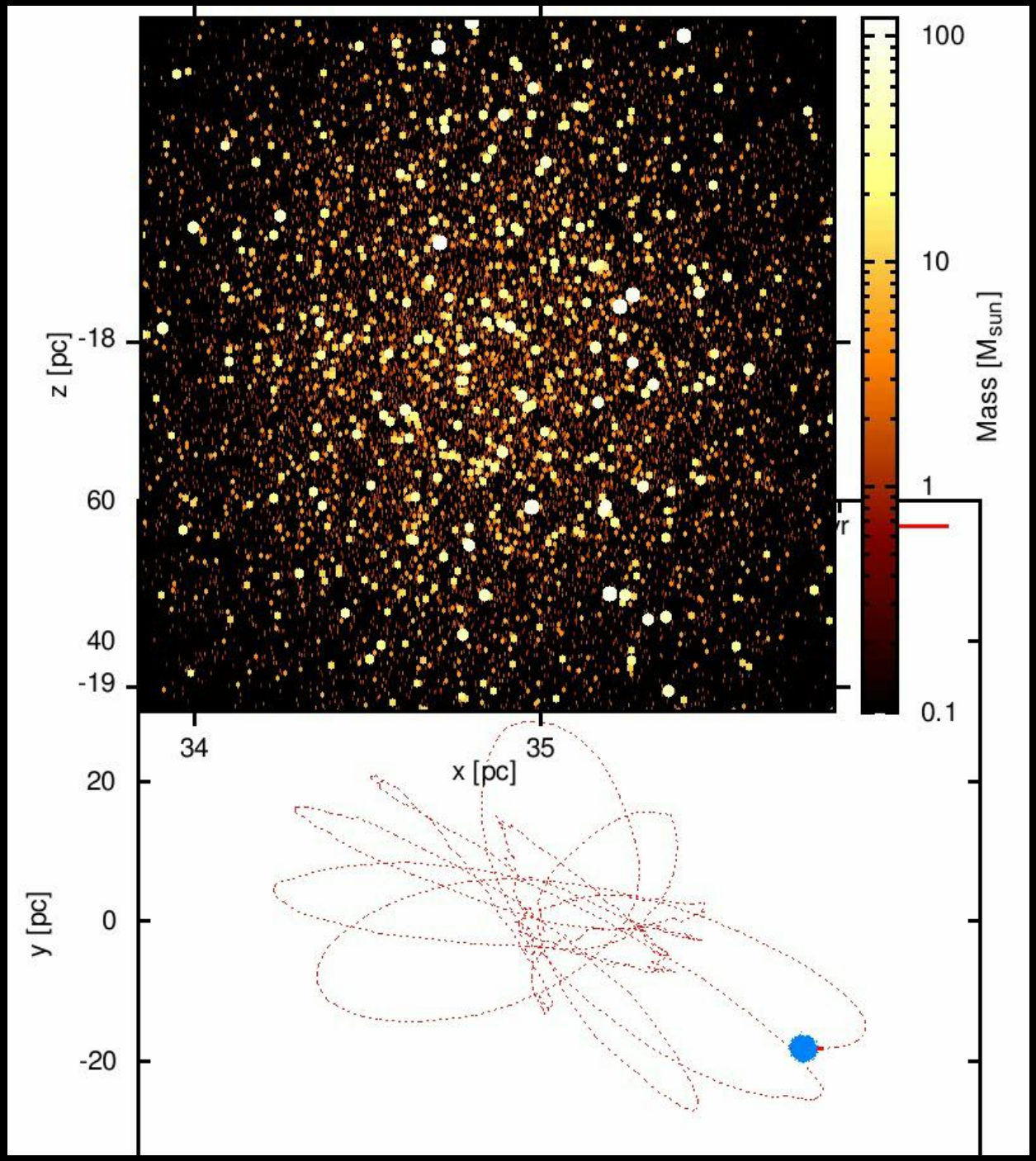




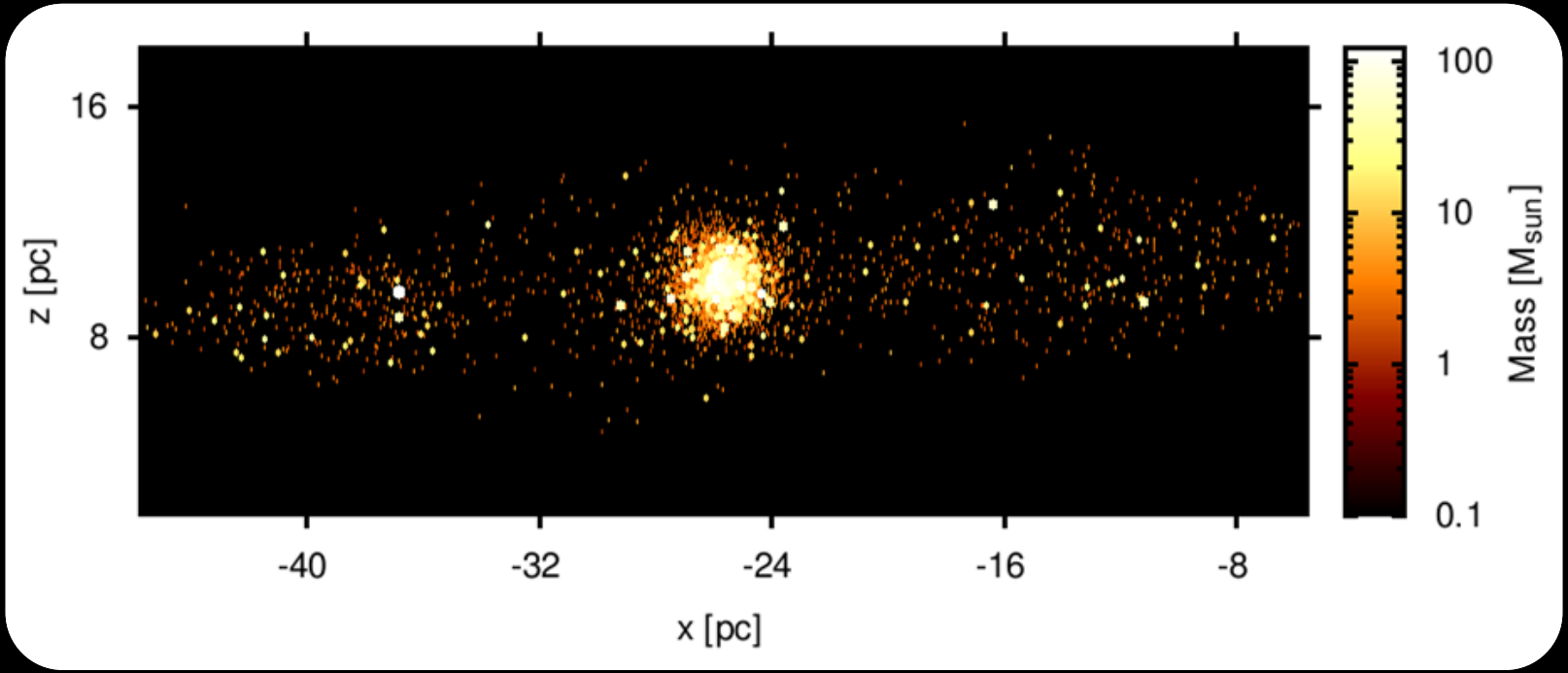
Orbit Models

- use best initial conditions from isolated models
- add GC potential
  - power-law
- calculate initial position
  - l.o.s. distance is free parameter
- evolve cluster along orbit
- stellar evolution is also included


z [pc]
7
6
-116
-115
x [pc]
100
10
1
0.1
Mass [M_sun]
orbit at t = 0.02 Myr
y [pc]
40
20
0
-20
-40
-100
-50
0
50
100
x [pc]


z [pc]
-18
60
40
-19
34
35
x [pc]
20
0
-20
y [pc]
100
10
1
0.1
Mass [M$_{sun}$]

„Best“ Model - Orbit Evolution



- most of the cluster mass is still bound at 2.5Myr
- tidal tails form (parallel to Galactic plane)
- cluster dissolves on a time scale of several tens of Myr

Summary and Outlook

- scale-free models (no SE, no orbit) can be used to constrain some of the cluster parameters
  - observed MF is mass-segregated standard IMF

- stellar evolution or mass-loss has a small effect
- orbit in the GC potential is important for the evolution
  - no best-fit for orbit models yet
  - some orbits can be ruled out, also a l.o.s.-position before the GC seems preferable

- open questions:
  - cluster membership by proper motion, also further out
  - Quintuplet