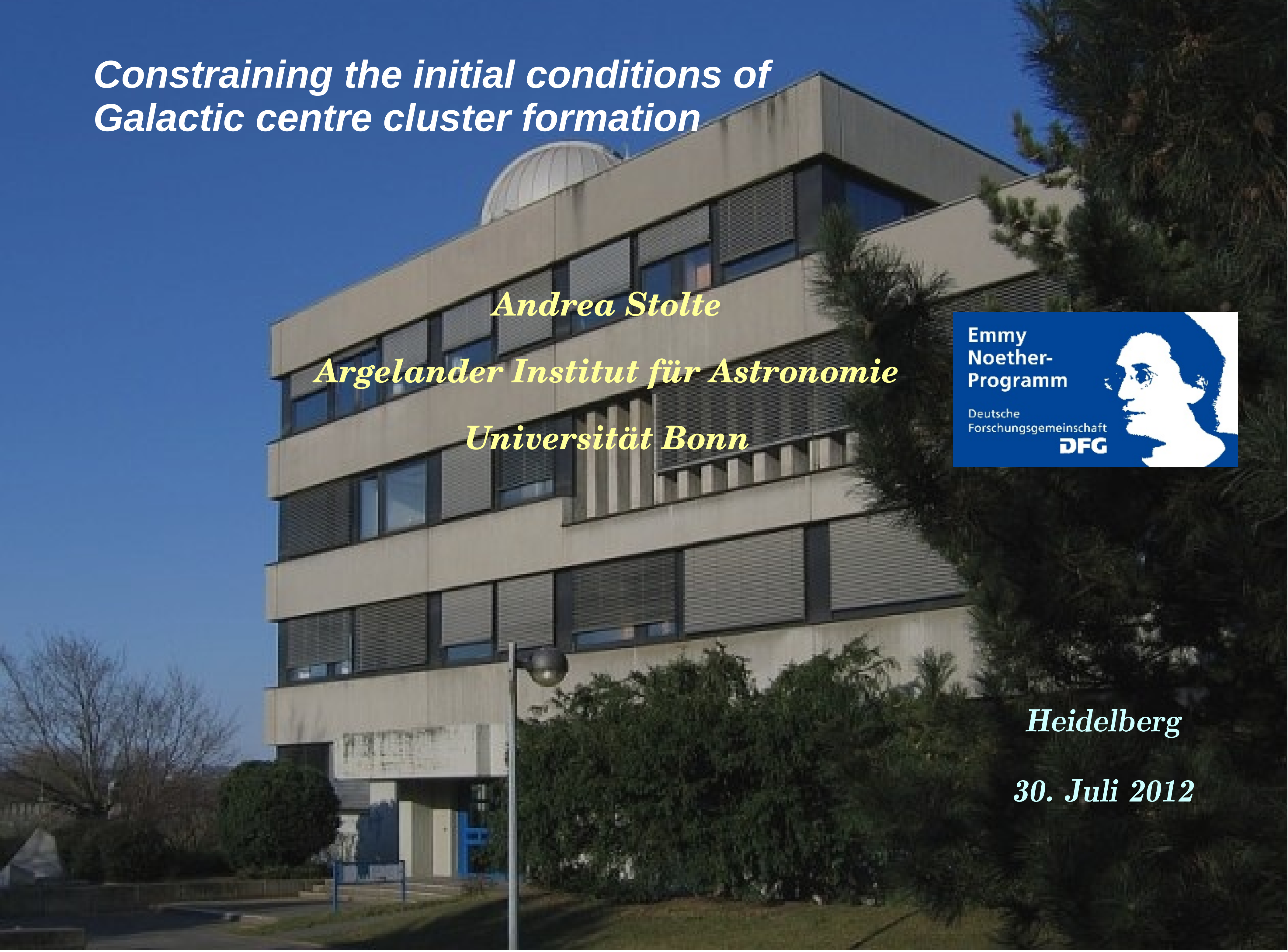
Constraining the initial conditions of Galactic centre cluster formation



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Constraining the initial conditions of Galactic centre cluster formation

Outline

Starburst cluster formation environments:
Galactic centre vs spiral arms

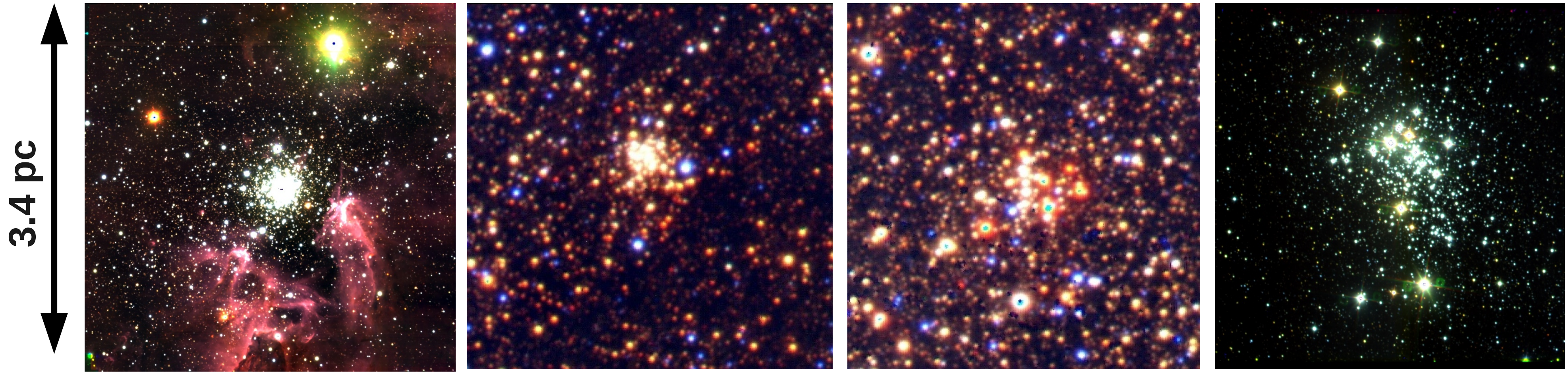
Galactic centre starburst clusters:
Observational constraints

Combining observations & simulations:
Constraints on initial conditions

Summary

Starburst Clusters are the most massive clusters forming in the Milky Way today

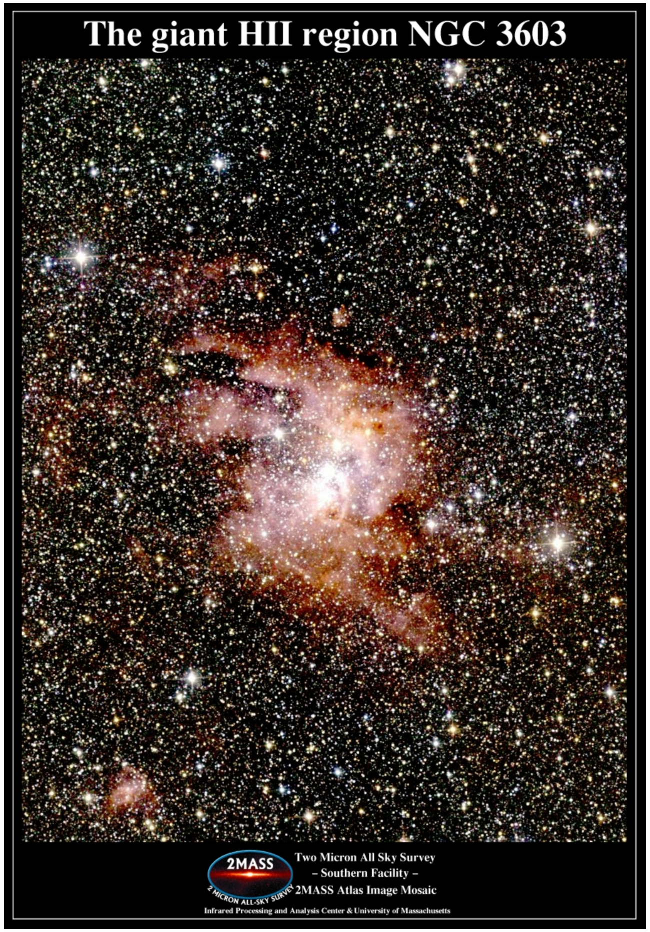
NGC 3603 YC | **Arches** | **Quintuplet** | **Westerlund 1**



Brandl et al. 1999 | *UKIDSS Galactic Plane Survey Lucas et al. 2008* | *Brandner et al. 2008*

Age	**1 – 2 Myr**	**2 – 3 Myr**	**3 – 5 Myr**	**4 – 5 Myr**
Mass	**17600 +- 3800**	**15000 +- 7000**	**> 6000 ?**	**50000 Msun**
	Rochau et al. 2010	*Clarkson et al. 2012*		*Gennaro et al. 2011*

Star cluster formation in spiral arms is an "isolated process"



Spiral arm cluster & star formation:

- core temperatures 10-20 K
- low magnetic field
- no background UV field

No nearby clouds, high-mass stars,
radiation sources, …

=> the star formation process is determined by internal properties of the cloud

1. cloud structure, density, temperature
2. cluster members, forming high-mass stars
3. internal dynamical processes

Star cluster formation in the Galactic center is a very “messy process”

High cloud/core temperatures

Interactions between clouds

Confinement by external magnetic fields

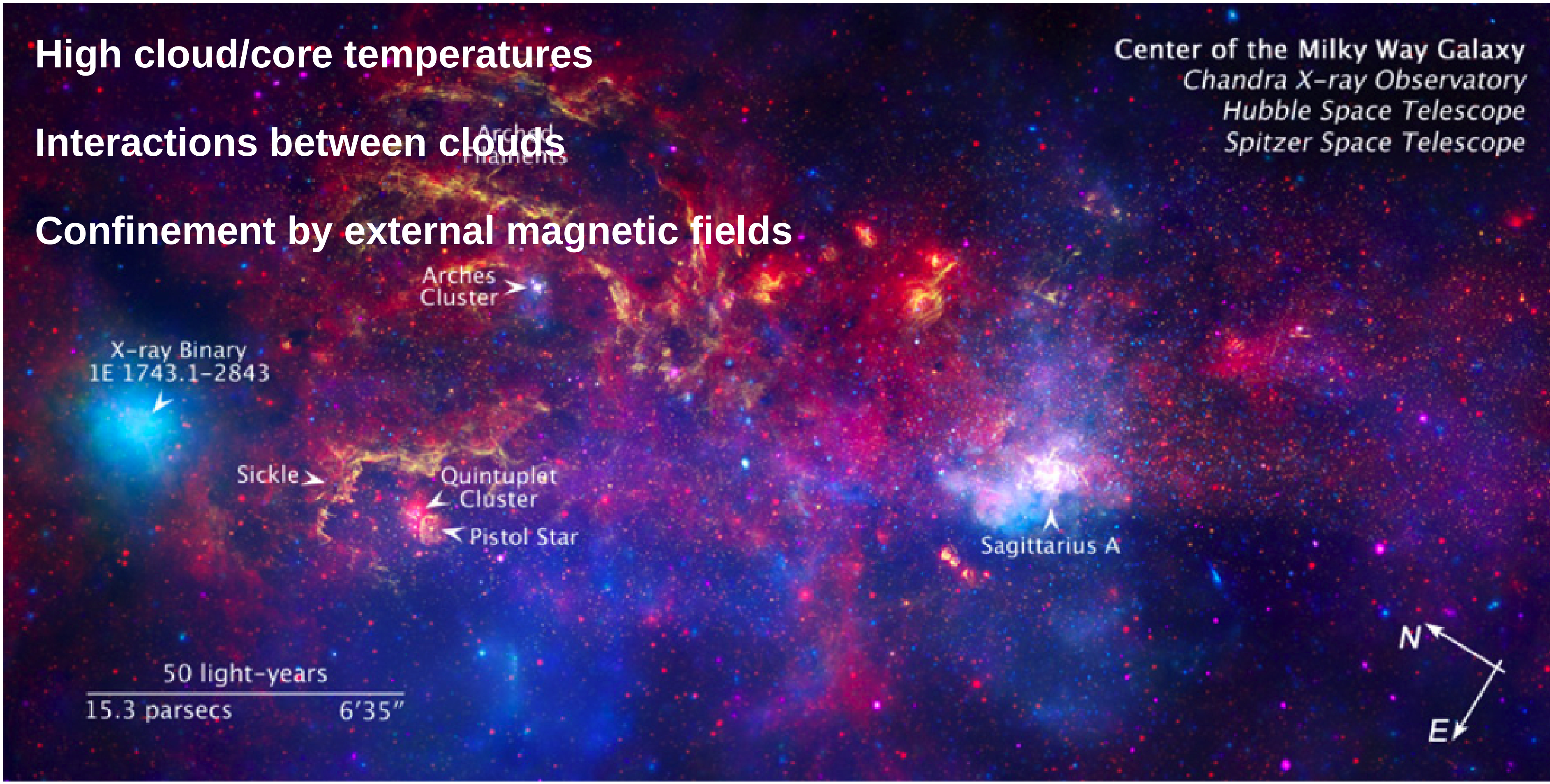
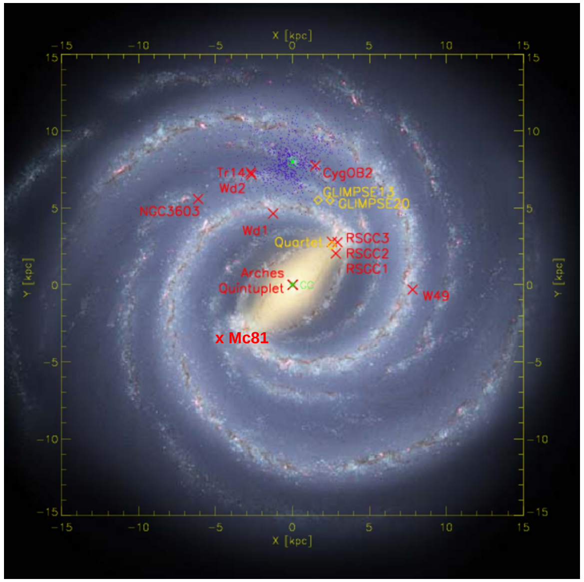


Image courtesy: Spitzer GLIMPSE & GC Paschen alpha surveys, D. Wang, A. Cotera, M. Morris et al.

Milky Way starburst clusters & location

Two very different formation environments:



<u>Spiral arm cluster & star formation:</u>

- core temperatures 10-20 K
- low magnetic field
- no background UV field

<u>Galactic center cluster & star formation:</u>

- core temperatures 70 K
- strong magnetic field
- UV field from multi-generations of high-mass stars

Expectation (in the simplest of worlds):

High temperatures & densities influence the Jeans mass,
and hence the smallest possible fragmenting element:

$$M_{Jeans} \sim T^{3/2} \rho^{-1/2}$$

=> the environment should influence the initial stellar mass distribution (IMF)

=> ***M_{Jeans}*** might increase from ***0.5 Msun to 5 Msun***

Morris 1993, Morris & Serabyn 1996

Indirect evidence for an overproduction of high-mass stars

A large fraction of young, high-mass stars is observed in the Galactic centre:

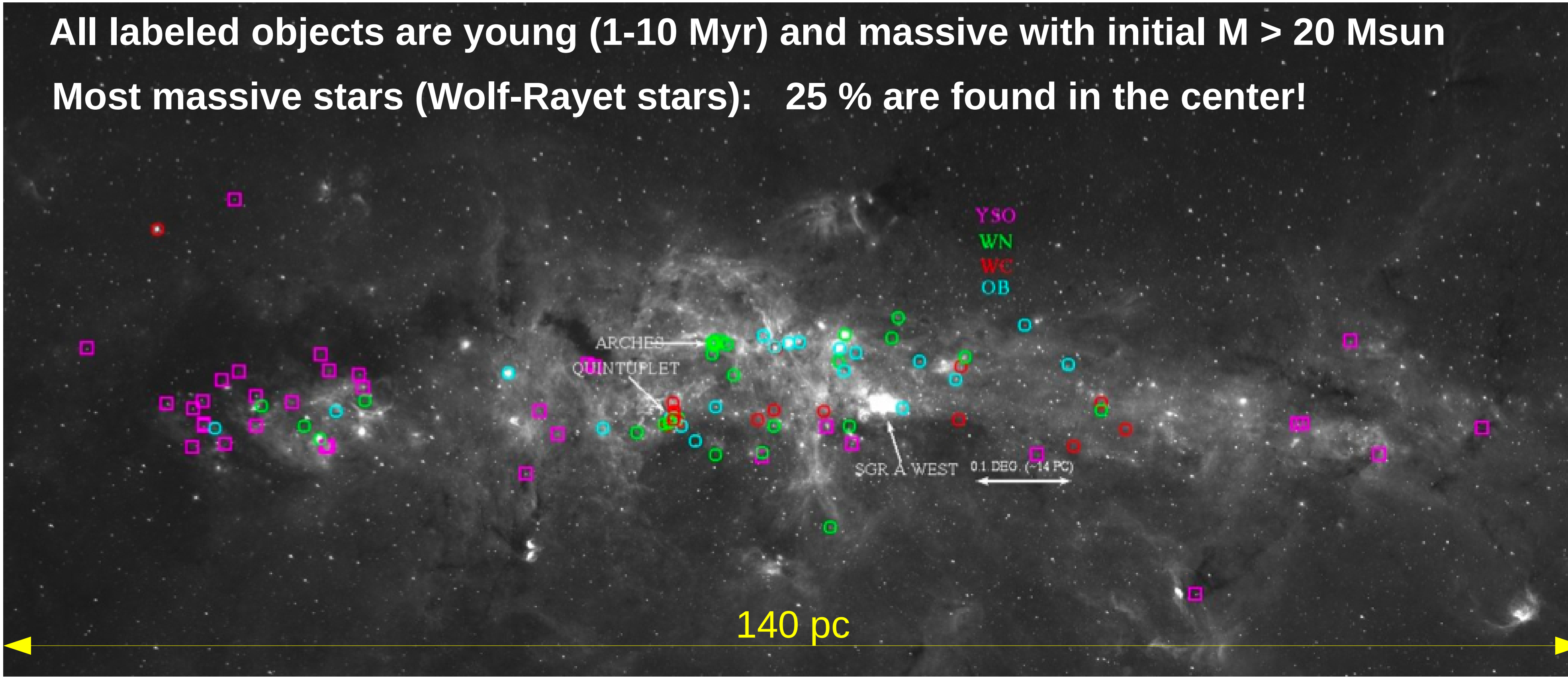


Image courtesy: A. Cotera with data from Mauerhan et al. 2010, 2011, Yusef-Zadeh et al. 2009

Star formation rate in the center of the Galaxy:

r < 200 pc	full MW disk	
0.14 Msun / yr	0.68 – 1.45 Msun / yr	*Yusef-Zadeh et al. 2009* *Robitaille & Whitney 2010*

=> 10-20 % of all stars for in the Galactic center environment

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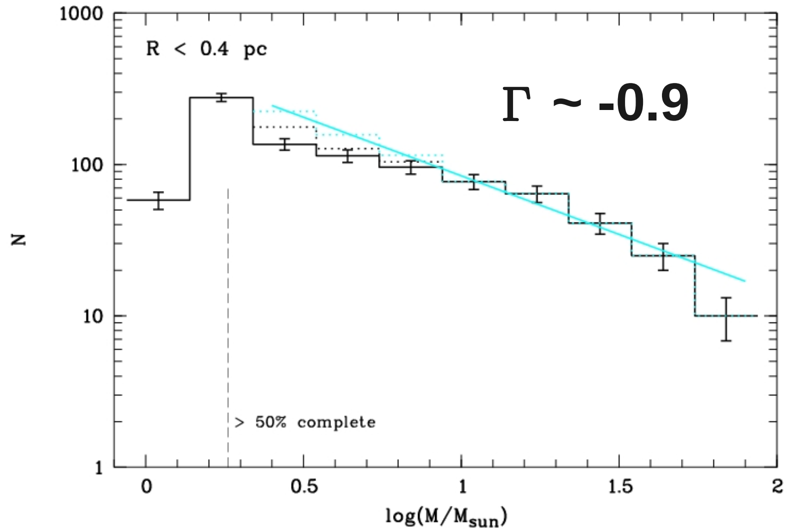
Constraints from observations:
Flat present-day mass functions in both Arches & Quintuplet



Arches

age 2.5 Myr

Observed:

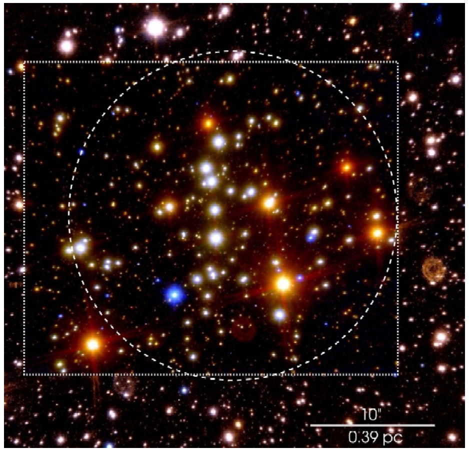
r < 0.4 pc:

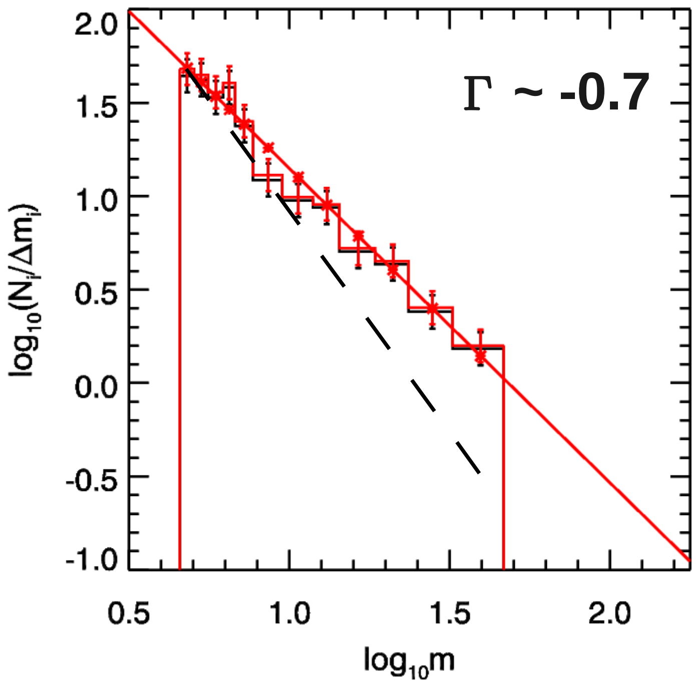
4 – 90 Msun

Γ ~ -0.9

(Salpeter --1.35)

Stolte et al. 2005





Quintuplet

age 4 Myr

Observed:

r < 0.5 pc:

5 – 40 Msun

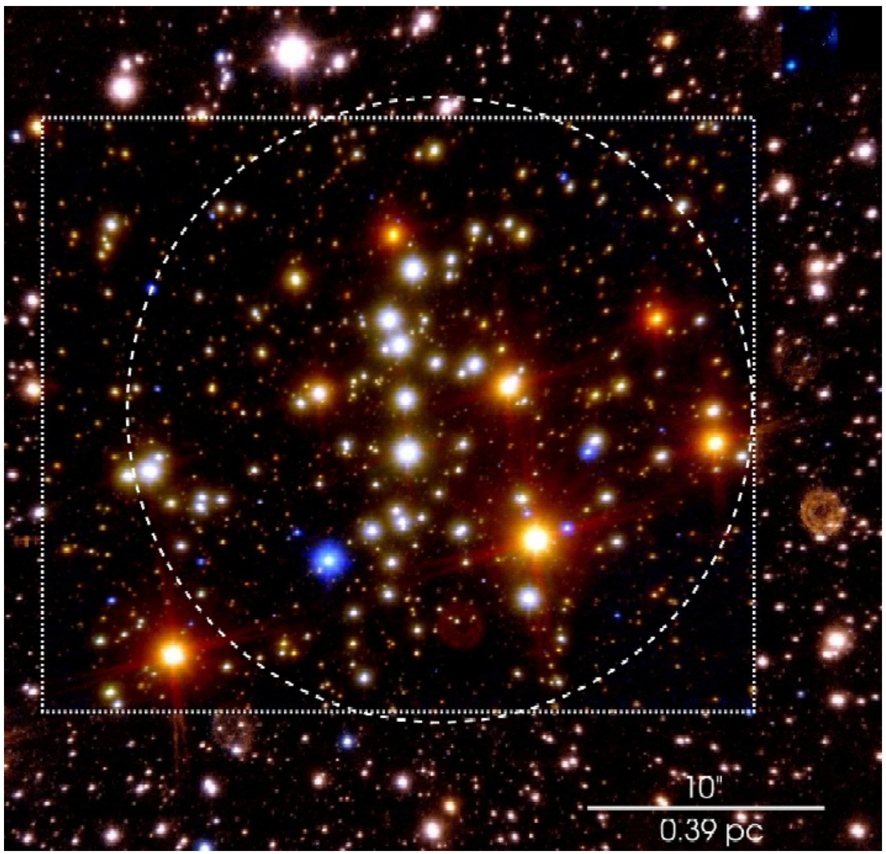
Γ ~ -0.7

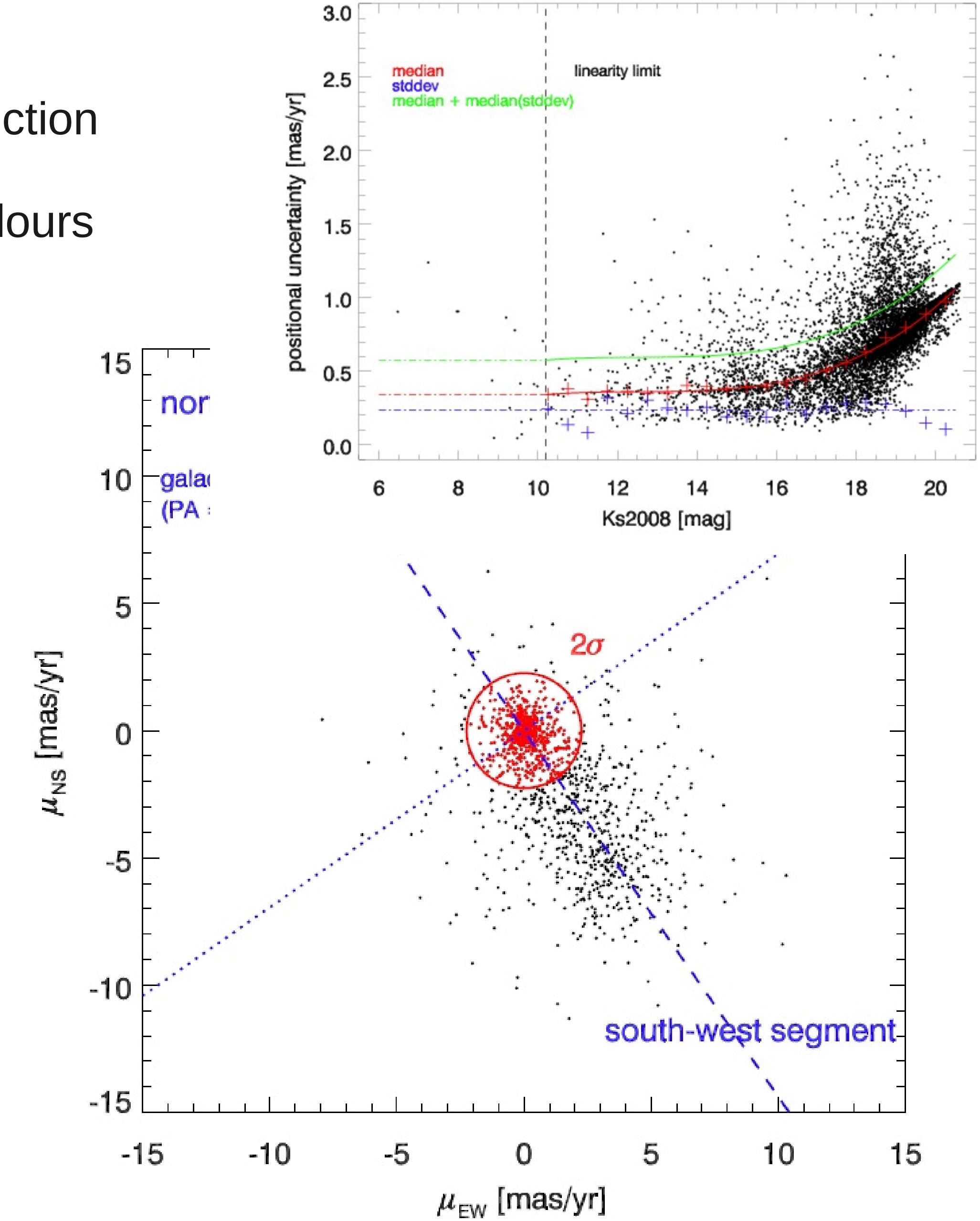
Hußmann et al. 2012

Proper motion membership as a tool to characterise starburst cluster populations

Towards an unbiased present-day mass function

- field stars in the Galactic center have colours comparable to cluster stars





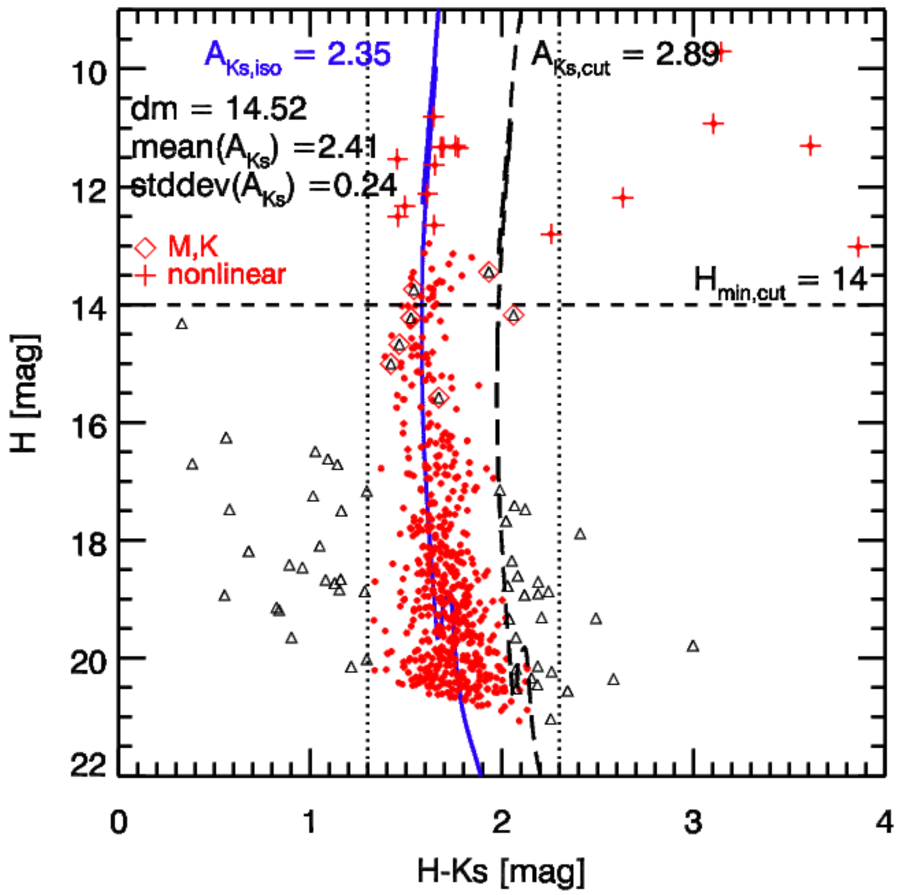
Hußmann et al. 2012

Efficiently selecting cluster members using proper motion

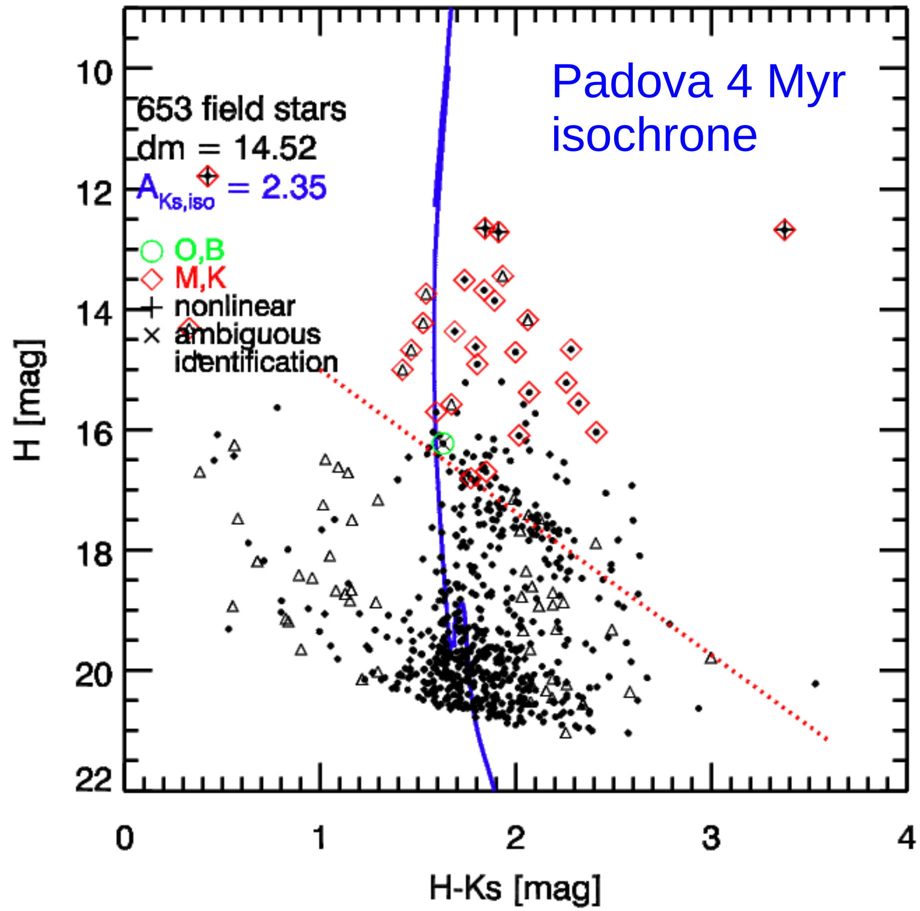
Towards an unbiased present-day mass function

- field stars in the Galactic center have colours comparable to cluster stars

Proper motion members



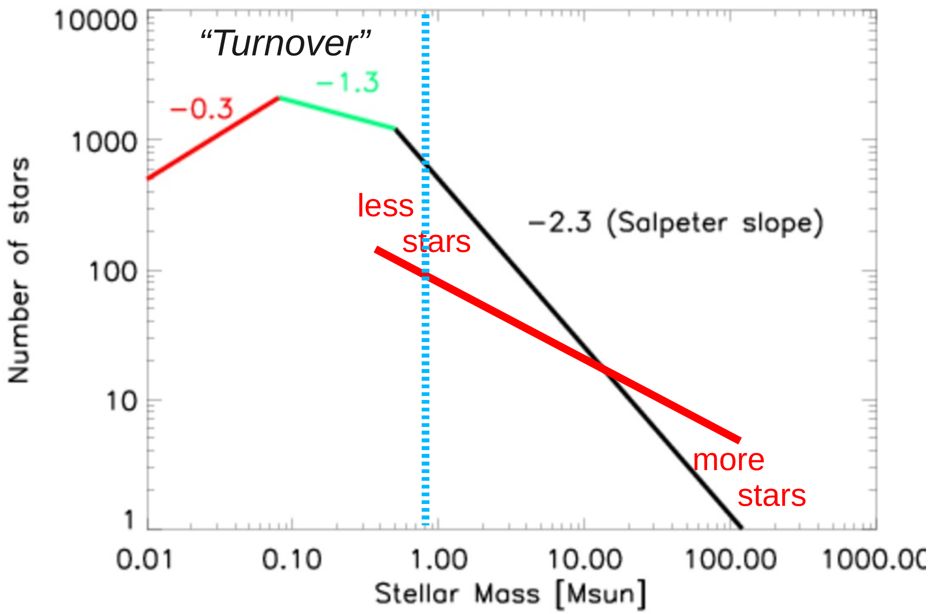
Proper motion non-members



Hußmann et al. 2012

What does "top-heavy MF" mean?

Power-law description of the IMF:



The turnover mass is the most frequent mass, hence called "the characteristic mass"

$$\xi(M)\Delta M = \xi_0 \left(\frac{M}{M_{sun}}\right)^{-2.35} \left(\frac{\Delta M}{M_{sun}}\right)$$

$\xi(M)$ Number of stars per ΔM

Starburst clusters:

- only the high-mass part is observed with the completeness limitations today

A top-heavy MF (present-day or initial) means the MF biased to high-mass stars:

- implies a *flatter slope* than Salpeter
- or a *truncation* at the low-mass end

The measured slope determines the total, *photometric cluster mass*

=> extrapolation of the observed PDMF

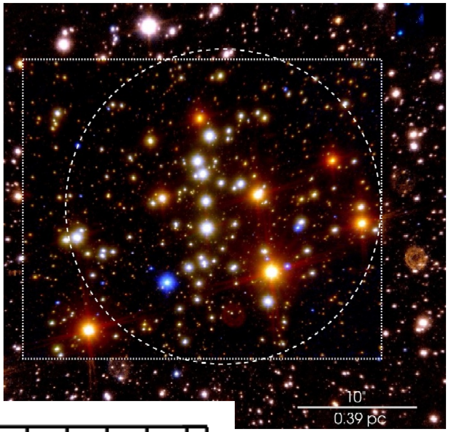
Salpeter 1955, Kroupa 2001

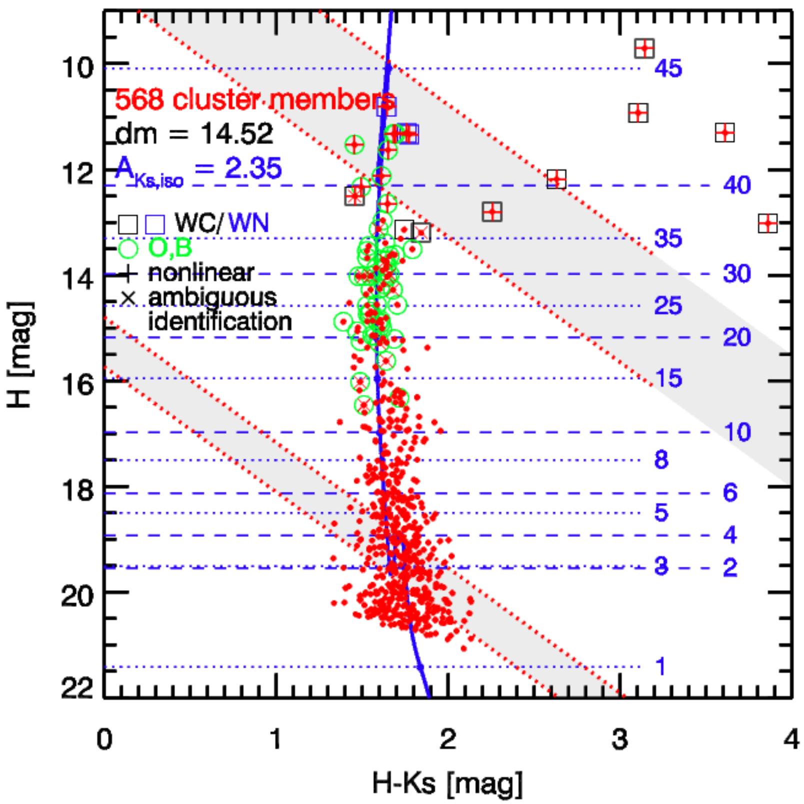
A flat (top-heavy) present-day MF in Quintuplet

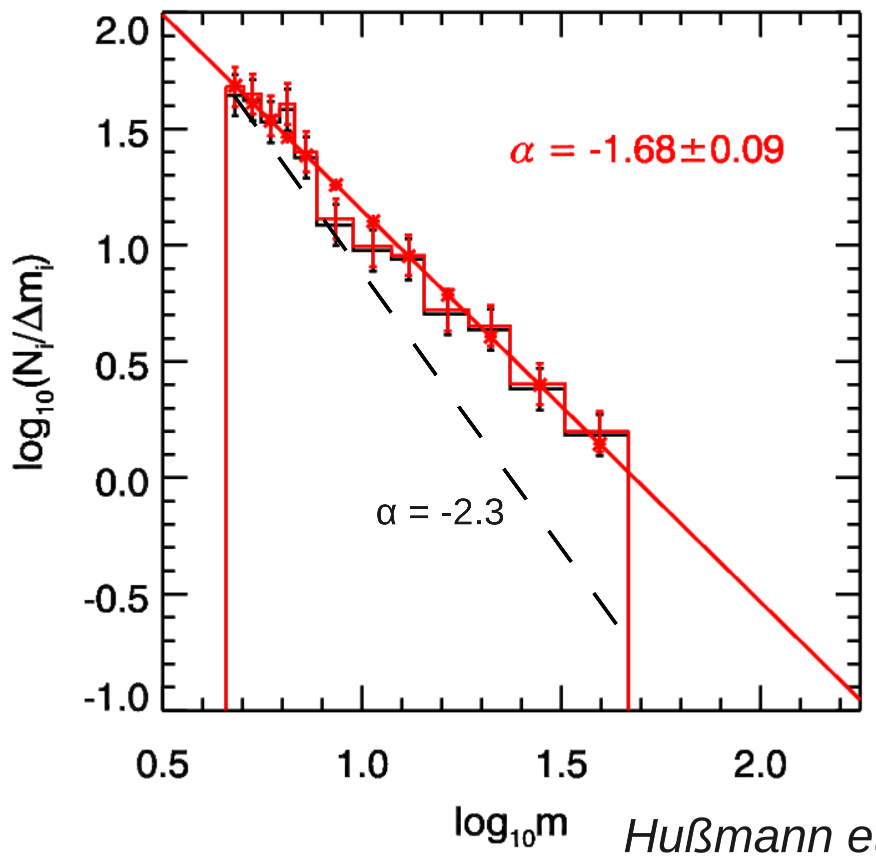
Quintuplet's mass function
from proper motion member selection

alpha = -1.68

for r < 0.5 pc







Hußmann et al. 2012

Problem:

Dynamical evolution influences the *present-day* MF in the cluster center

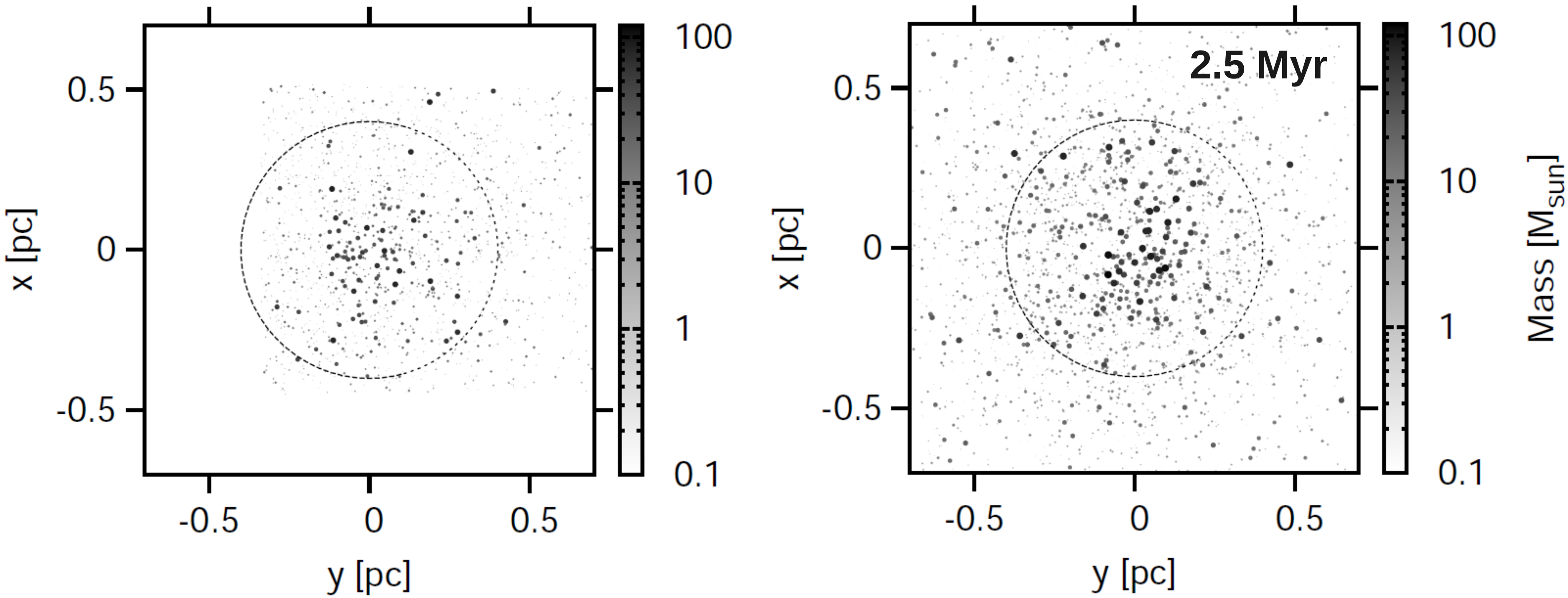
Dynamical evolution as a source for the slope variation

Arches full N-body simulations:

Constraining the initial conditions of cluster evolution

Harfst, Portegies Zwart & Stolte 2010 & in prep

220 massive stars: **observed** **simulated**



Question:

Can the present-day MF be caused by dynamical evolution, or is it an intrinsic property of star formation in the GC?

Dynamical evolution as a source for the slope variation

Arches full N-body simulations:

Constraining the initial conditions of cluster evolution

Harfst, Portegies Zwart & Stolte 2010 & in prep

220 massive stars: **observed**

r < 0.4 pc
4 – 90 Msun

Γ ~ -0.9

(Salpeter –1.35)

King profile W0 = 3

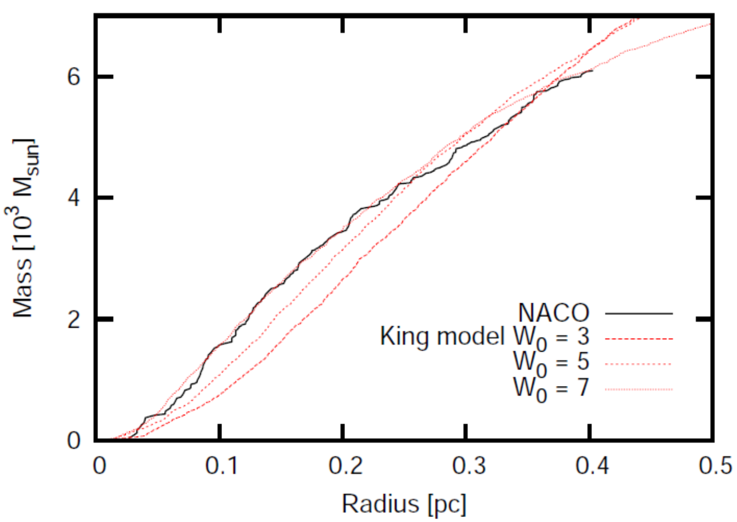
simulated

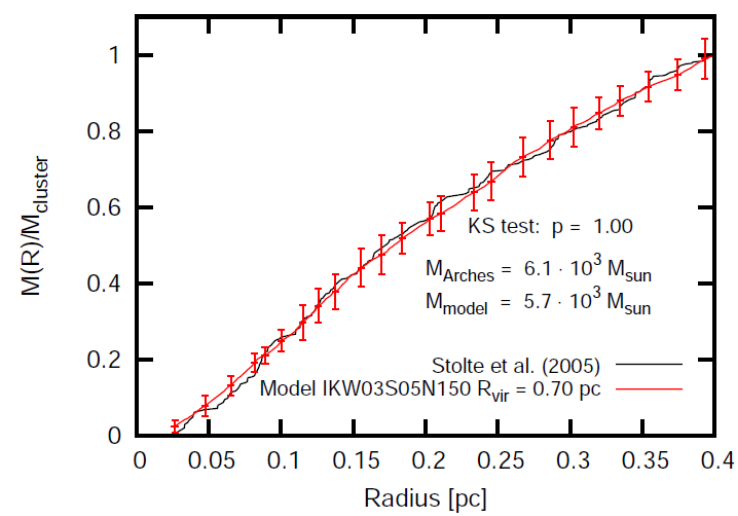
0.1 < R_{vir} < 1 pc

-1.35 < Γ < -0.9

20000 < M_{cl} < 50000 Msun

W0 = 3 - 7





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Dynamical evolution as a source for the slope variation

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Harfst, Portegies Zwart & Stolte 2010 & in prep

220 massive stars: **observed**

Constraints:

*** radial mass profile**

*** measured mass in r < 0.4 pc**

*** present-day MF slope**

Additional parameter:

*** number of stars M > 10 Msun**

observed vs initial:

- ejections
- crowding

simulated

Goodness of fit parameters (KS)

*** radial mass profile**

$$f_{profile} = p$$

p: probability that both profiles are drawn from the same population

*** measured mass in r < 0.4 pc**

$$f_M = 1 - \left| 1 - \frac{M_{model}}{M_{Arches}} \right|$$

*** present-day MF slope**

$$f_{IMF} = 1 - \left| 1 - \frac{\Gamma_{model}}{\Gamma_{Arches}} \right|$$

Dynamical evolution as a source for the slope variation

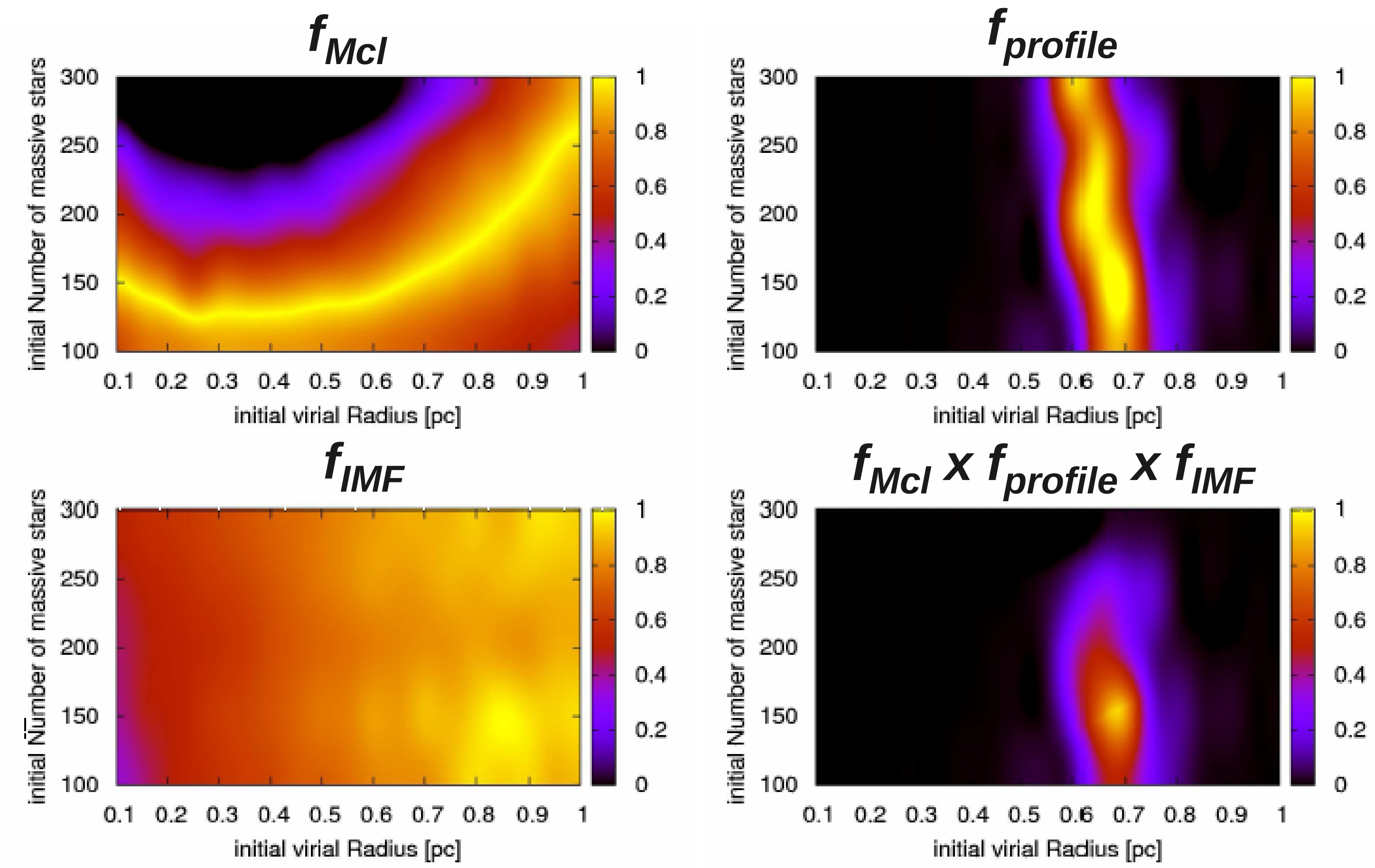
Arches full N-body simulations:

Constraining the initial conditions of cluster evolution

Harfst, Portegies Zwart & Stolte 2010 & in prep

W0 = 3

Γ_{IMF} = -1.35



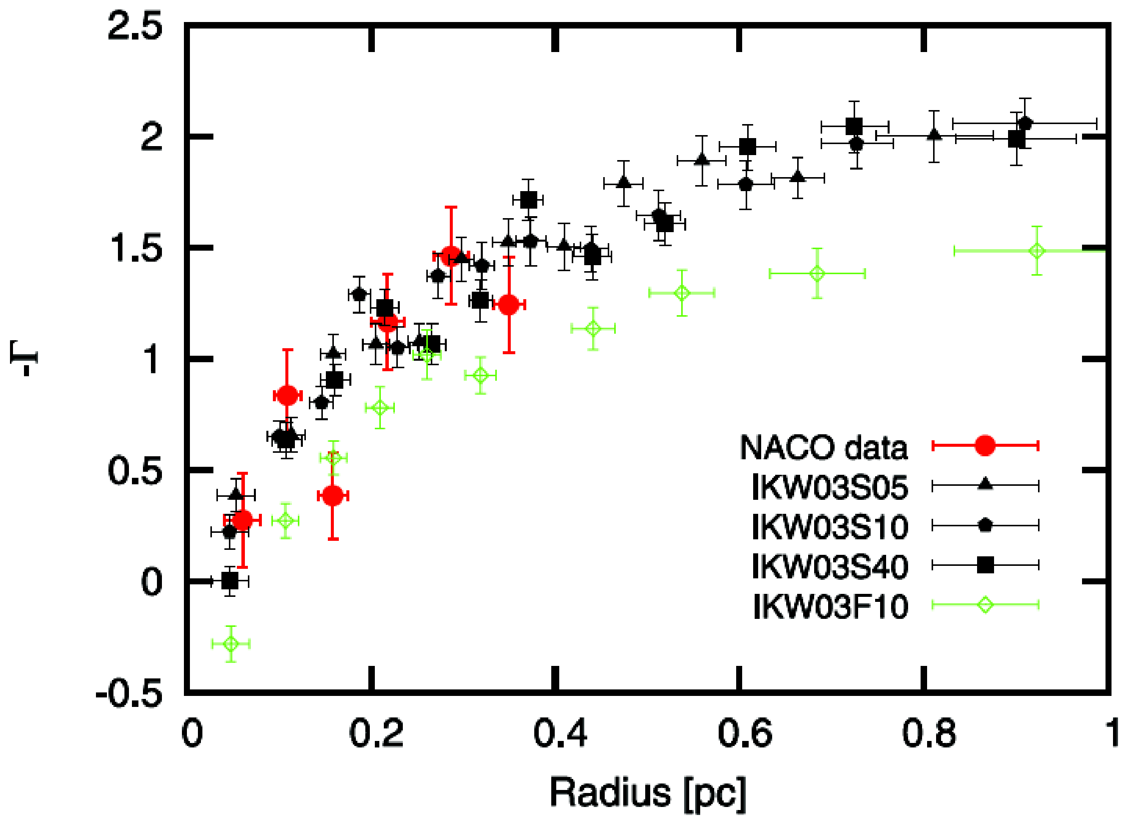
The best-fitting model can be used to constrain the cluster's initial conditions.

Arches full N-body simulations:

Constraining the initial conditions of cluster evolution

Harfst, Portegies Zwart & Stolte 2010 & in prep

Wo = 3
Gamma IMF = -1.35



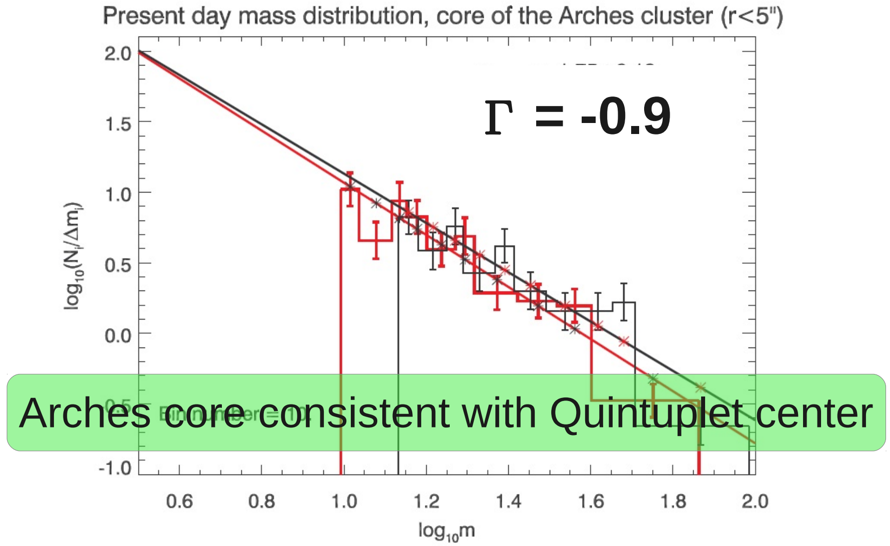
Prediction: a steeper PDMF at large radii

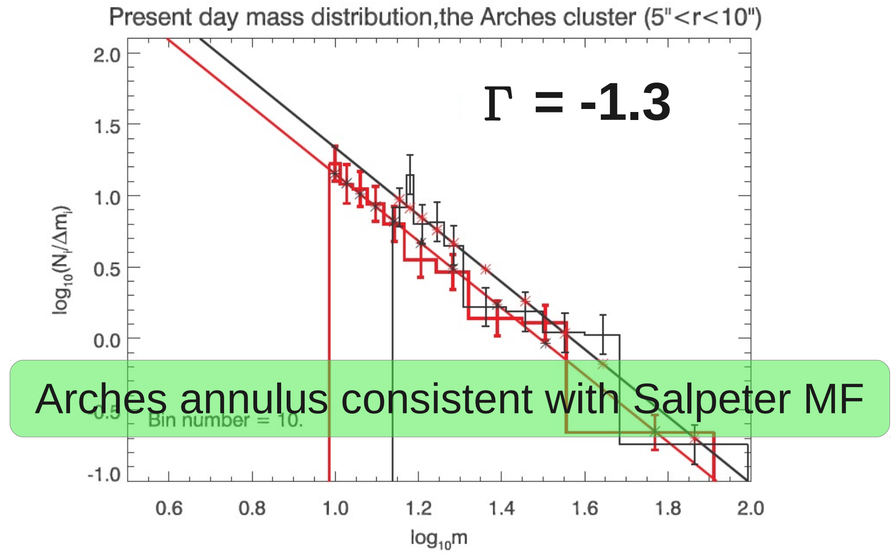
Conclusion:

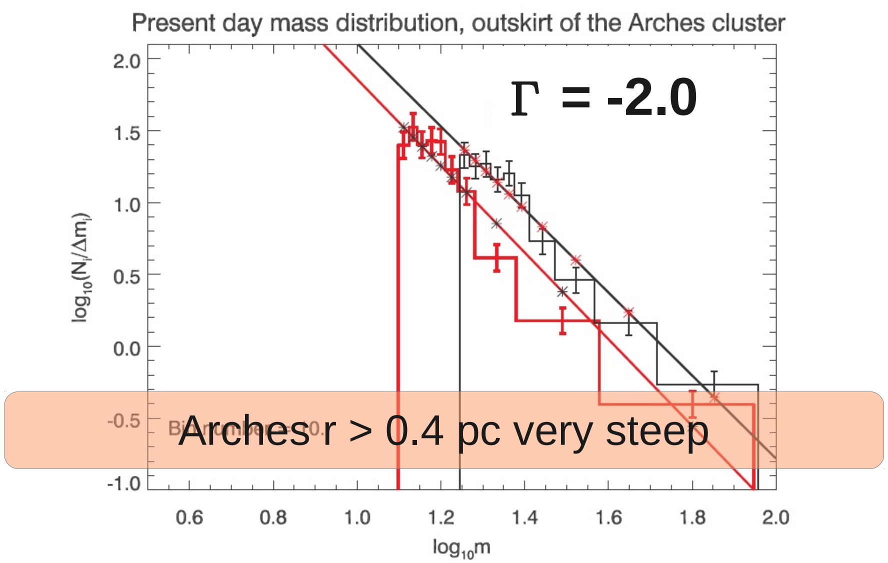
The flat present-day MF in the cluster center can be explained by dynamical evolution.

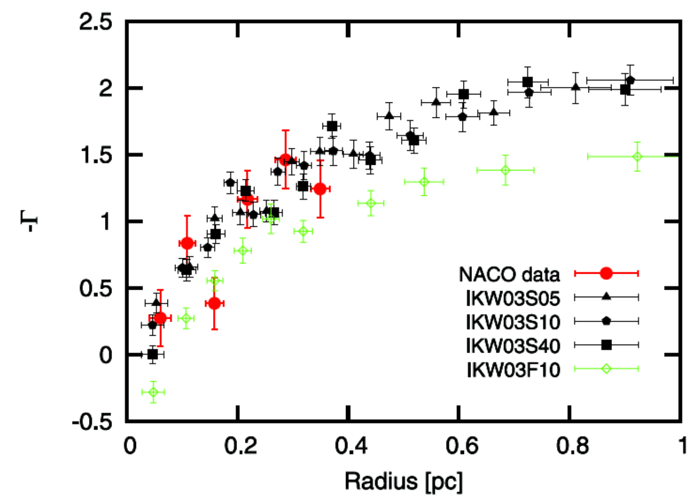
Observed radial variation of the present-day mass function

The slope of the present-day mass function steepens as a function of radius exactly as predicted by the simulations.









Habibi et al., in prep

Summary

<u>**Present-day mass functions**</u>

Starburst clusters are mass segregated

*** PDMFs are flattened in their cores**
*** PDMFs are steepened near the tidal radius**

<u>**Local variations in the PDMF**</u>

Local PDMFs are not representative of the *initial* stellar mass functions in starburst clusters

<u>**Dynamical simulations**</u>

Short dynamical timescales of < Myr imply the need for simulations:

Dynamical segregation is sufficient to explain their MF slopes

<u>**Galactic centre vs spiral arm SF**</u>

Present-day MFs & simulations provide no direct evidence for a different mode of SF in the Galactic centre environment.

<u>Open issue:</u>
A low-mass cutoff cannot yet be excluded.

Thank you very much
for your attention!