Investigating mass segregation in the core of newly formed clusters

(Bound/Unbound)

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15 June 2017

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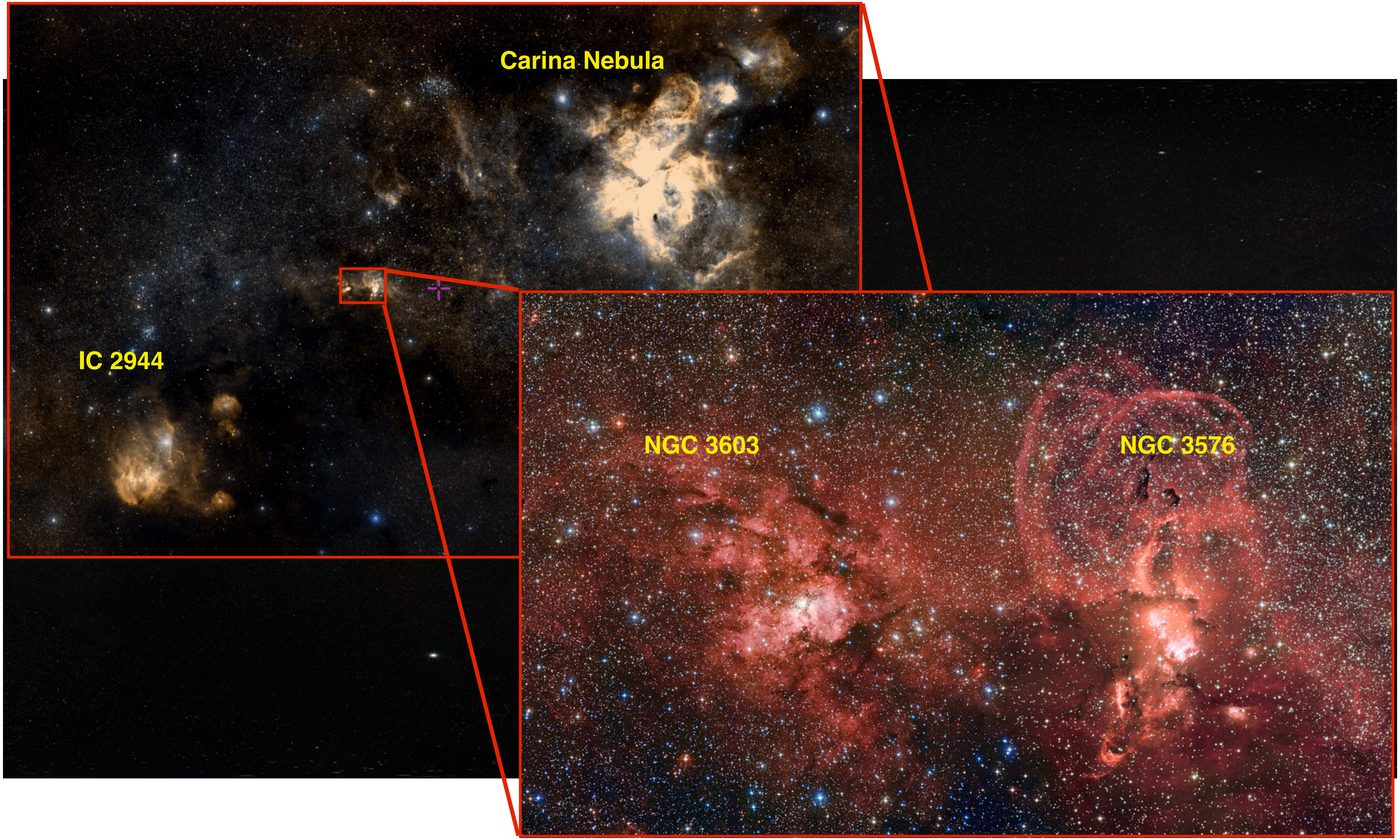
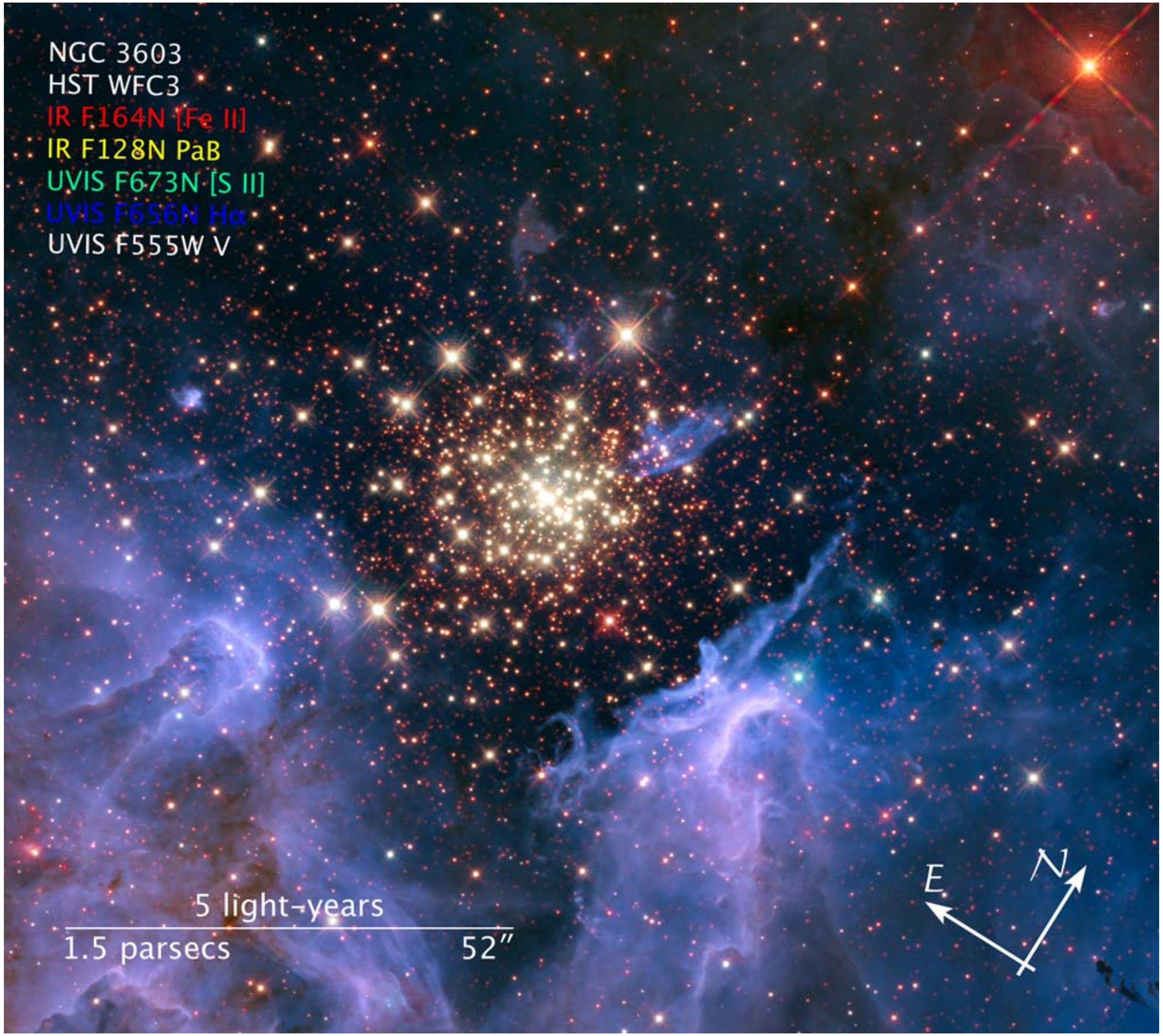
Outline

- Observational evidence for mass segregation (NGC3603, R136)
  - Locally variable Mass-function
  - Minimum Spanning Tree (MST) method
- Make Your Synthetic Observation (MYSO) first!

- Massive stars tend to be located in the centre of the cluster
- Mass-segregation can be the result of dynamical interaction between stars
- In newly formed clusters, mass-segregation can be primordial: massive stars form in the centre of the cluster

NGC 3603





$M_{total} \sim 10^4 M_{\odot}$

$Age \sim 1 - 2Myr$

$Dis \sim 6 - 7Kpc$

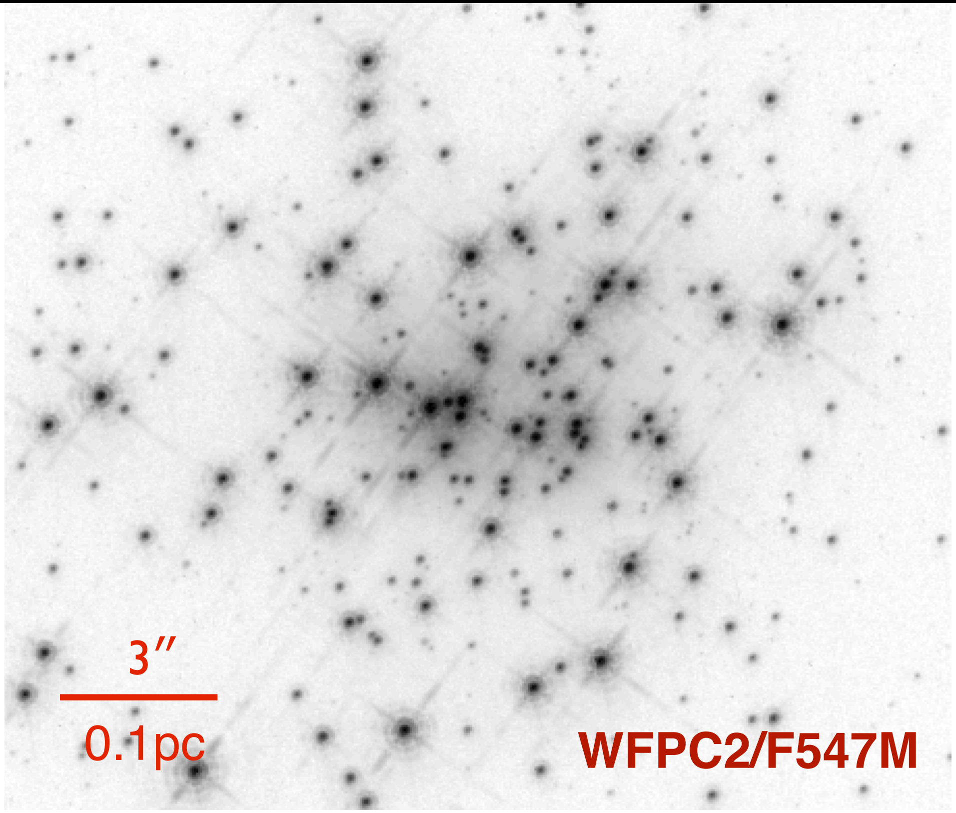
$Constellation : Carina$

NGC 3603

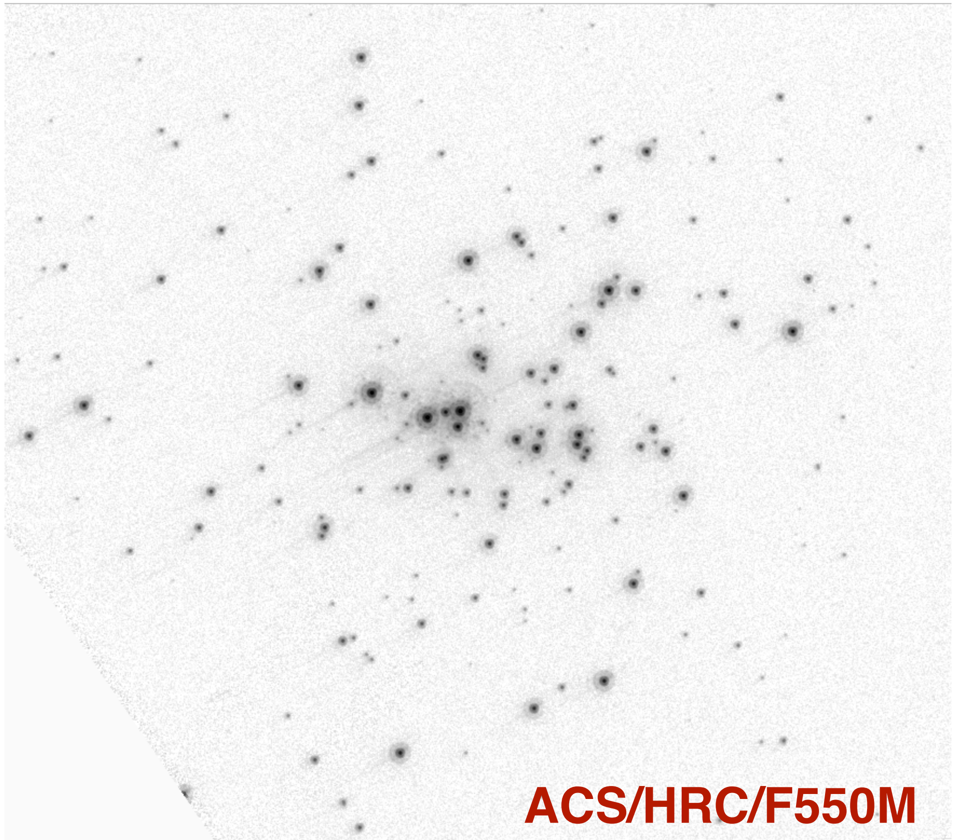
MF slope	condition	Reference
-0.73	$(1-30)\,M_{\odot}$	[Eisenhauer et al.1998]
-0.9	$(2.5-100)\,M_{\odot}$	[Sung & Bessell2004]
-0.5 ± 0.1	$r<6''$	[Sung & Bessell2004]
-0.8 ± 0.2	$6''-12''$	[Sung & Bessell2004]
-1.2 ± 0.2	$r>12''$	[Sung & Bessell2004]
-0.91 ± 0.15	$(0.4-20)\,M_{\odot}$	[Stolte et al.2006]
-0.31	$0-5''$	[Harayama et al.2008]
-0.55	$5''-10''$	[Harayama et al.2008]
-0.72	$10''-13''$	[Harayama et al.2008]
-0.75	$13''-30''$	[Harayama et al.2008]
-0.26	$0-5''$	[Pang et al.2013]
-0.55	$5''-10''$	[Pang et al.2013]
-0.76	$10''-15''$	[Pang et al.2013]

Different observations

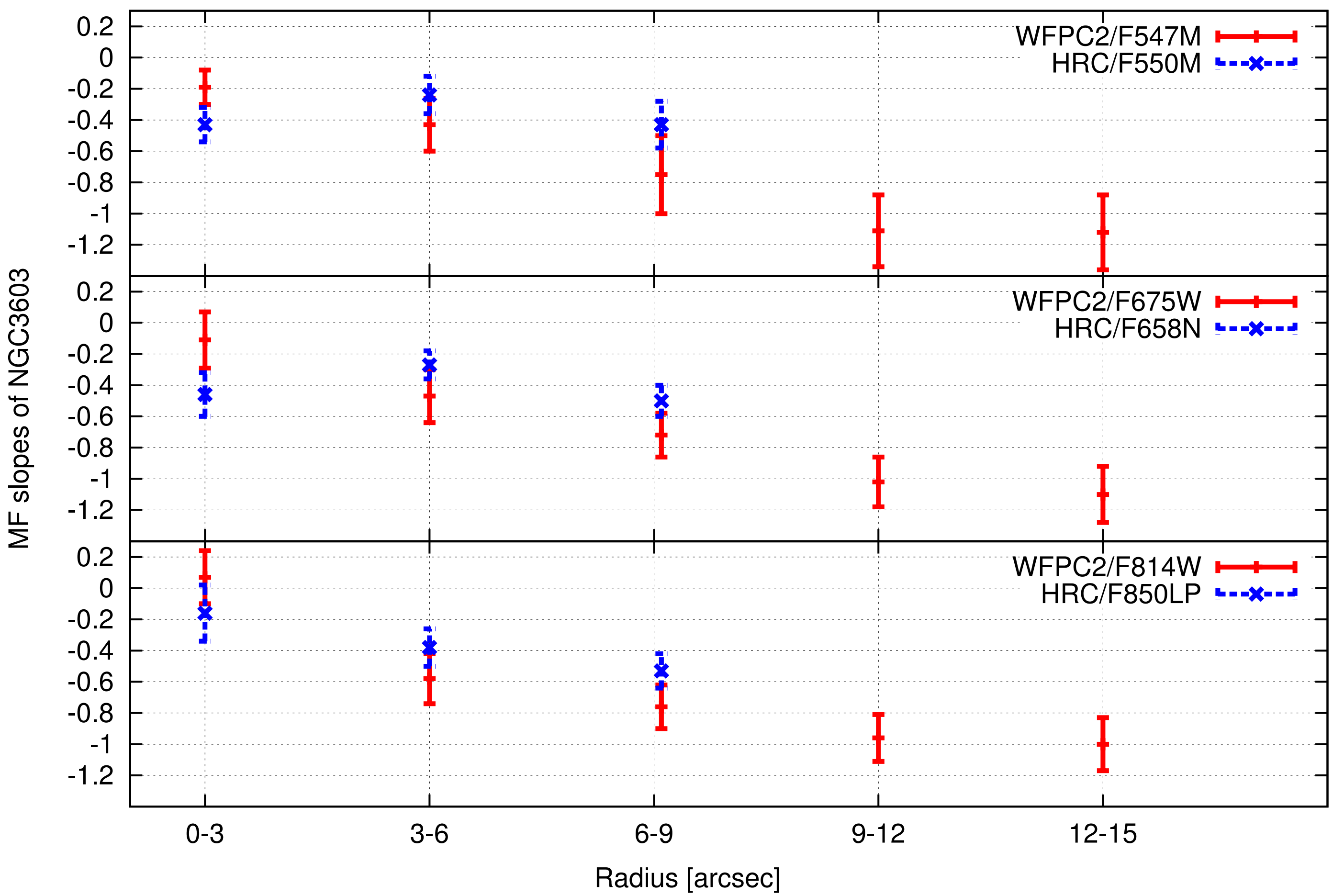
Different MF slopes



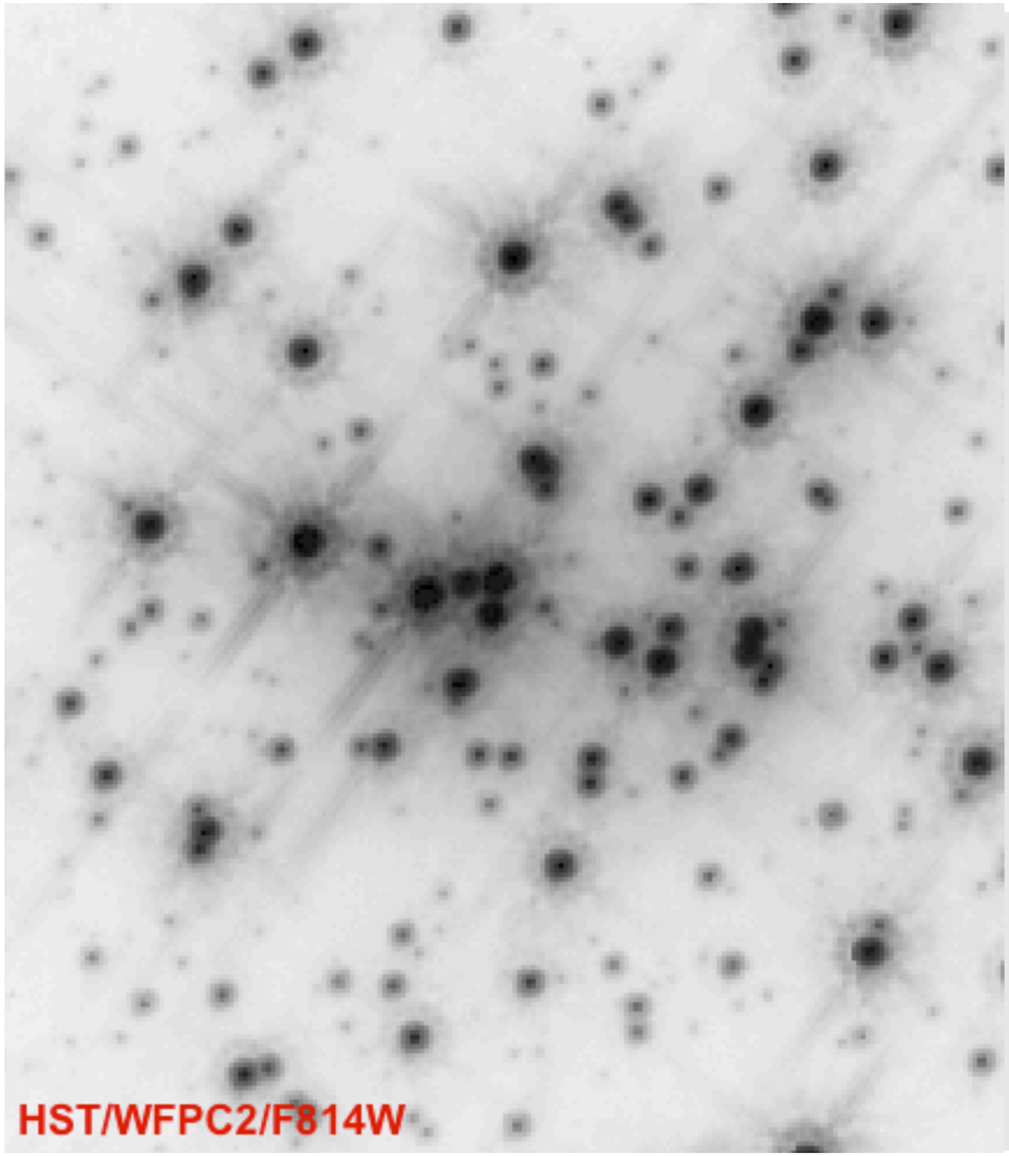
WFPC2
Filters: V,R,I
50mas/pix

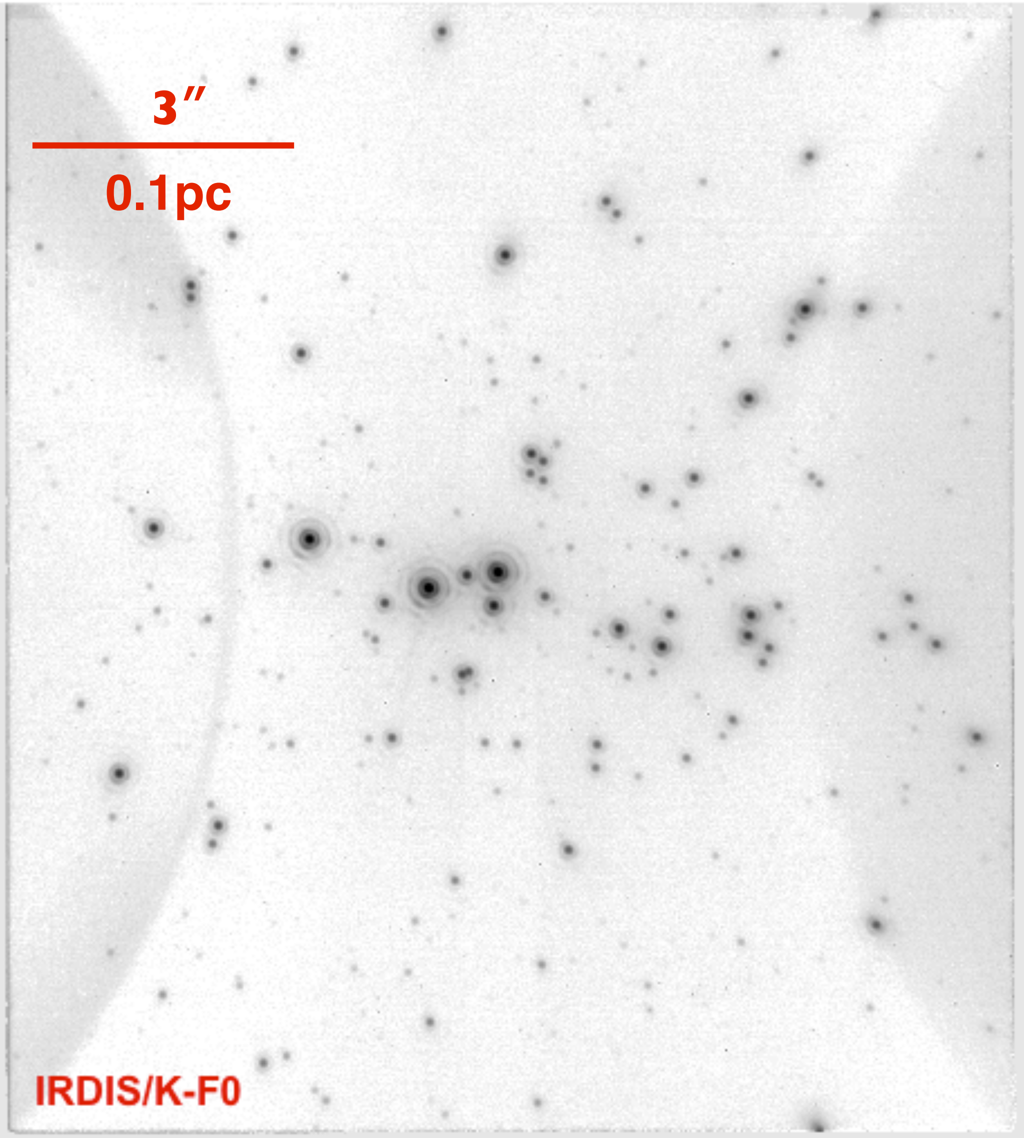


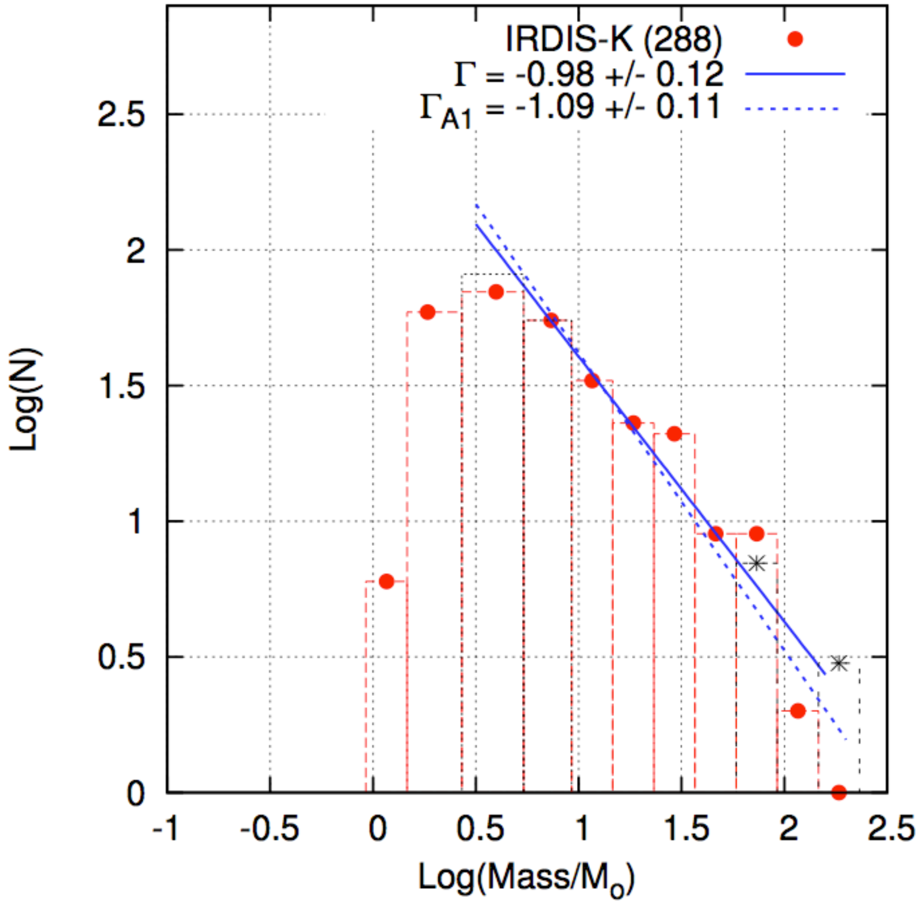
ACS/HRC
Filters: Ux,U,B,V,R,I
25mas/pix

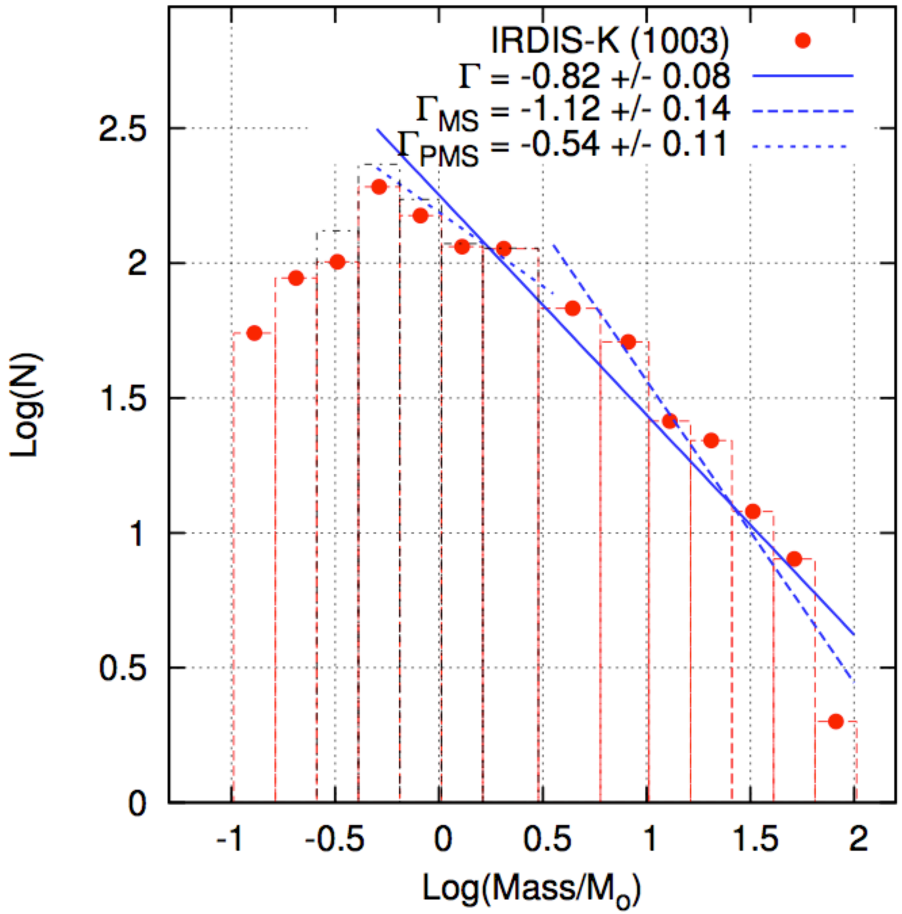


WFPC2 shows the decreasing trend in MF slope... signature of mass-segregation BUT this is not the case for HRC data


HST/WFPC2/F814W


3″
0.1pc
IRDIS/K-F0





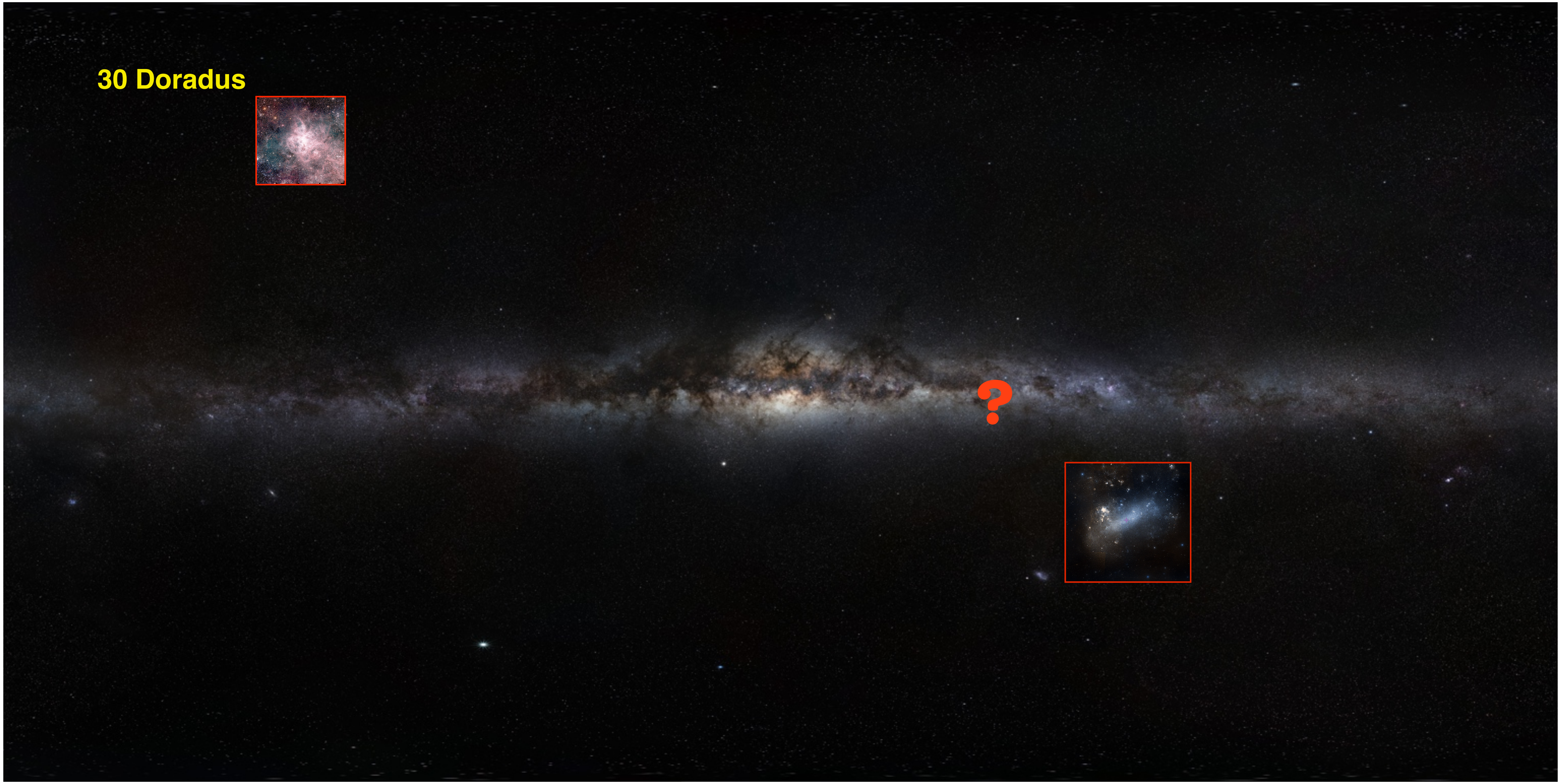
No signature of mass segregation in the core of NGC 3603:

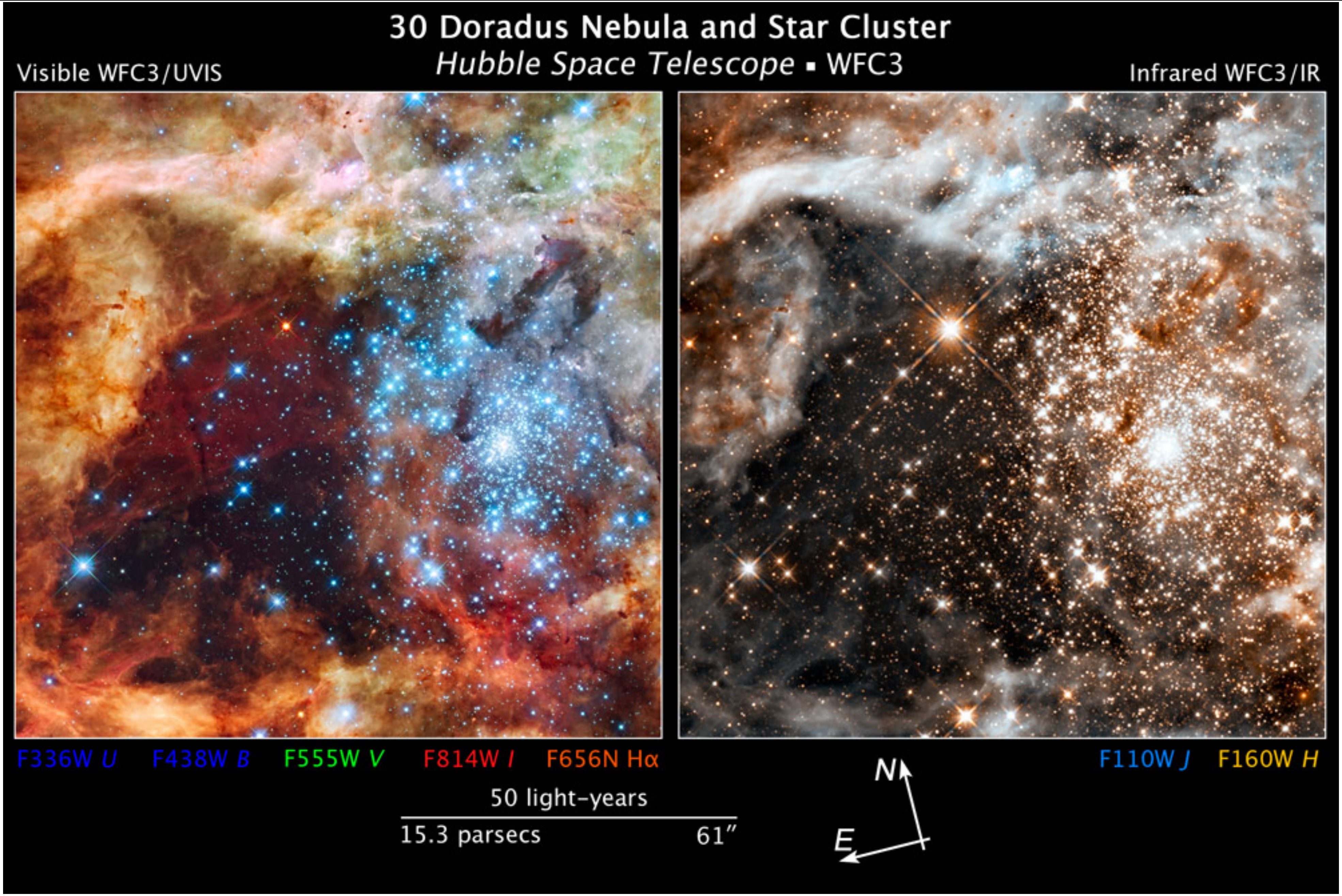
1) The MF slope in its very core is not flatter than the next radial bin

2) Both slopes are similar to the MF values found in previous works for the outer regions

[Khorrami et al., 2017, A&A, 588, id.L7]

R 136



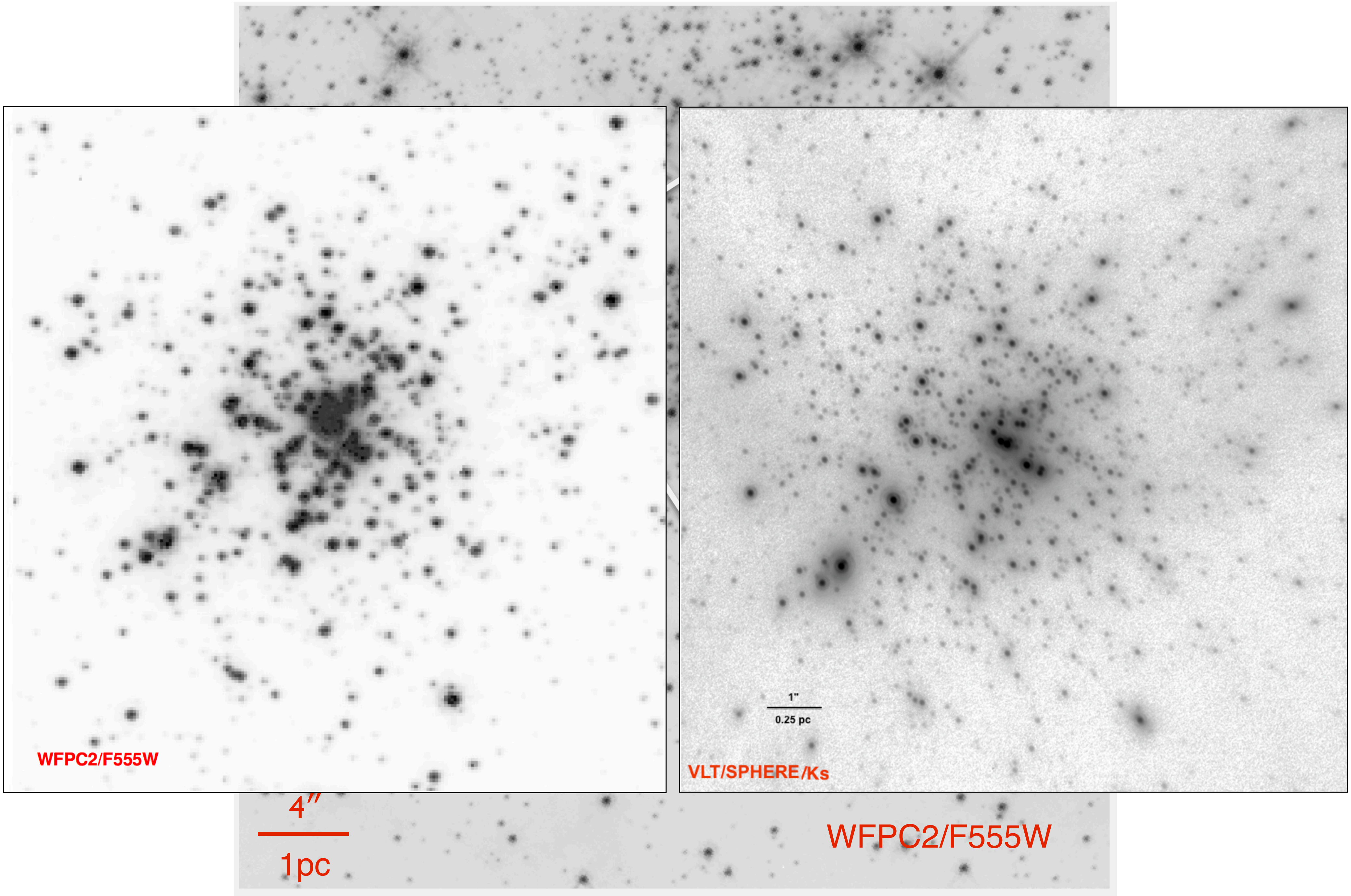


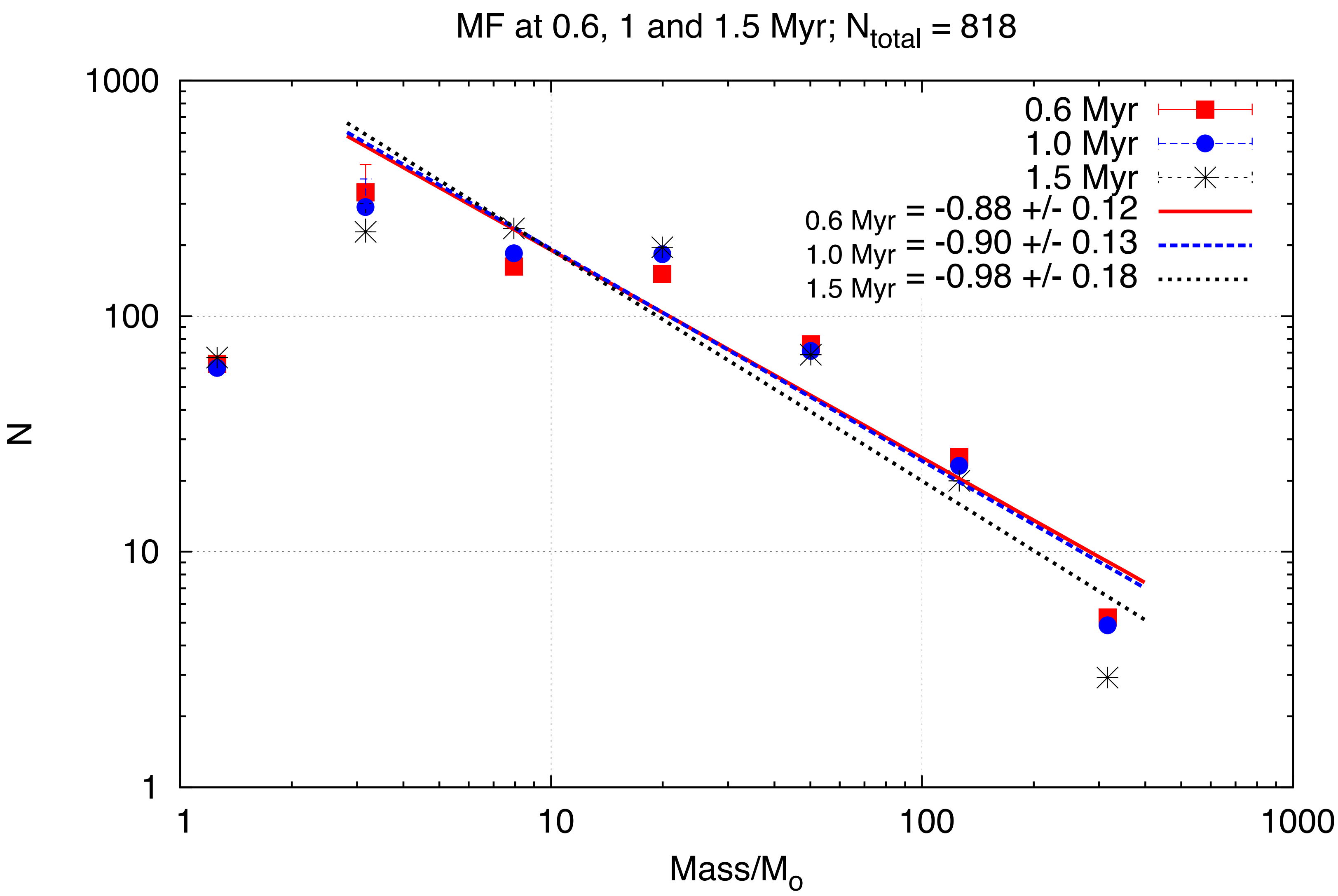
$Dis \sim 50Kpc$
$Constellation : 30Doradus$

$M_{total} \sim 10^5 M_{\odot}$
$Age \sim 2 - 3Myr$

Mass function slopes for R 136 from previous analyses.

MF slope	Condition	Reference
−0.90	(20–70) $M_\odot$ $r < 3\farcs3$	Malumuth & Heap (1994)
−1.89	(20–70) $M_\odot$ $3\farcs3 < r < 17\farcs5$	Malumuth & Heap (1994)
−1.0 ± 0.1	(2.8–15) $M_\odot$ $2\farcs0 < r < 18\farcs8$	Hunter et al. (1996)
(−1.3)–(−1.4)	(15–120) $M_\odot$	Massey & Hunter (1998)
−1.59	$r < 1\farcs6$	Brandl et al. (1996)
−1.33	$1\farcs6 < r < 3\farcs2$	Brandl et al. (1996)
−1.63	$3\farcs2 < r$	Brandl et al. (1996)
−1.17 ± 0.05	$4\farcs6 < r < 19\farcs2$	Selman et al. (1999)
−1.37 ± 0.08	$15'' < r < 75''$	Selman et al. (1999)
−1.28 ± 0.05	(2–6.5) $M_\odot$ $4'' \lesssim r \lesssim 20''$	Sirianni et al. (2000)
−1.2 ± 0.2	(1.1–20) $M_\odot$ $20'' < r < 28''$	Andersen et al. (2009)


WFPC2/F555W
1"
0.25 pc
VLT/SPHERE/Ks
4"
1pc
WFPC2/F555W



[Khorrami et al., 2017, A&A, 602, A56]

Synthetic observations (**M**ake **Y**our **S**ynthetic **O**bservation)

Inputs:

Stars information (from N-body): 3D position and Velocity, Mass, age, metallicity
Cloud information (from SPH): 3D position, particle's mass, smoothing lengths

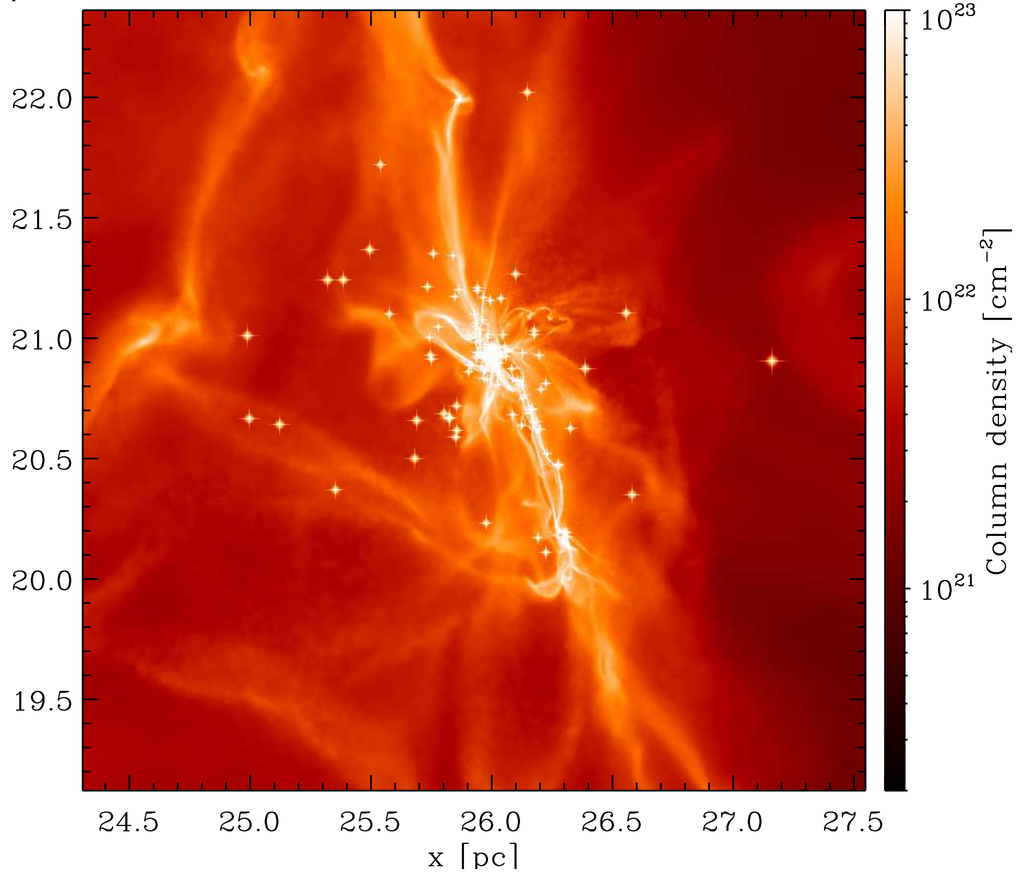
Observational Filter (from the list)
Imaging angular resolution AND Spectroscopic resolution

Distance of the centre of mass
FoV

R_v for extinction
Adaptive optics: seeing and SR

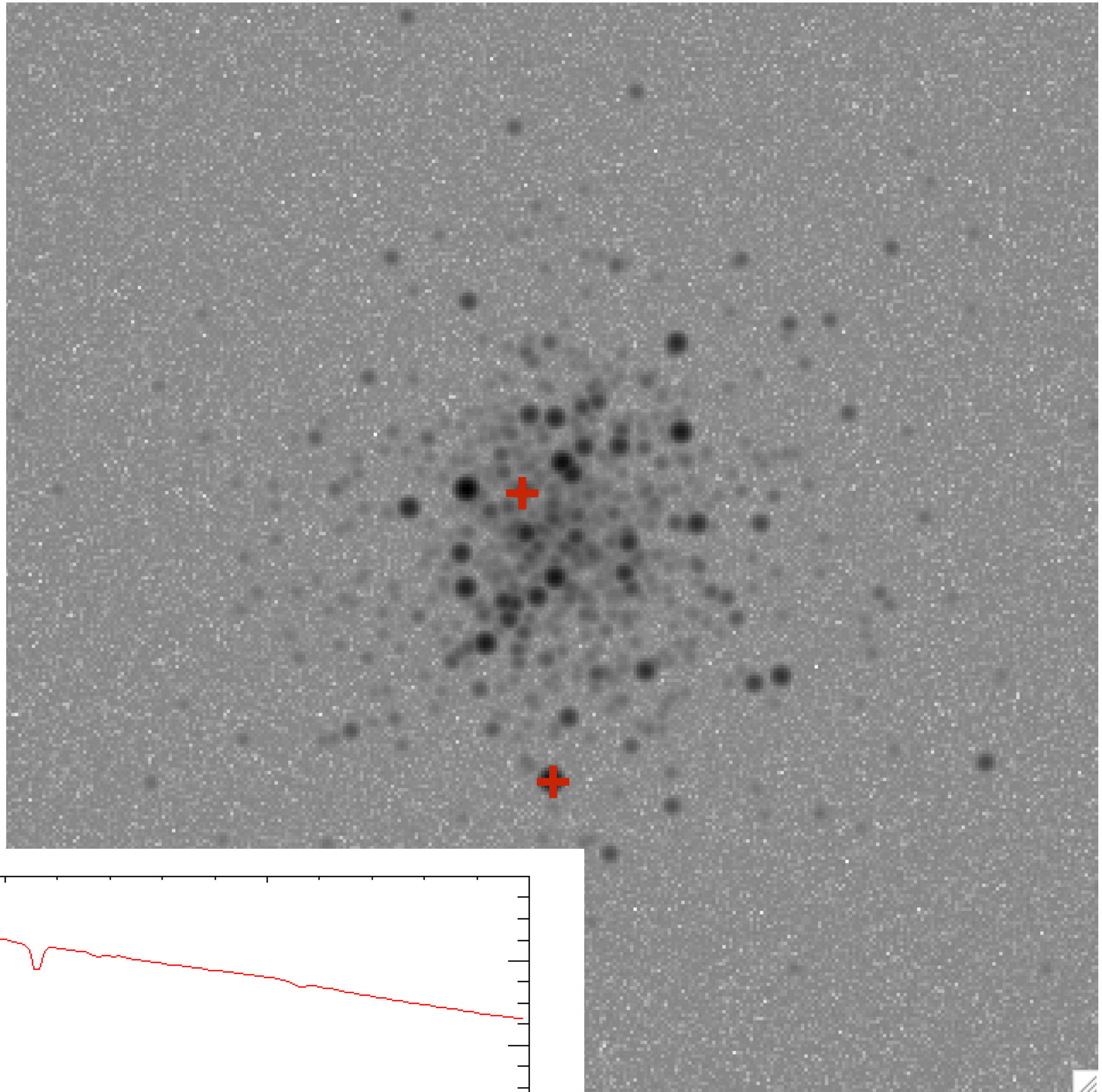
OB-treatment: TLUSTY model atmosphere

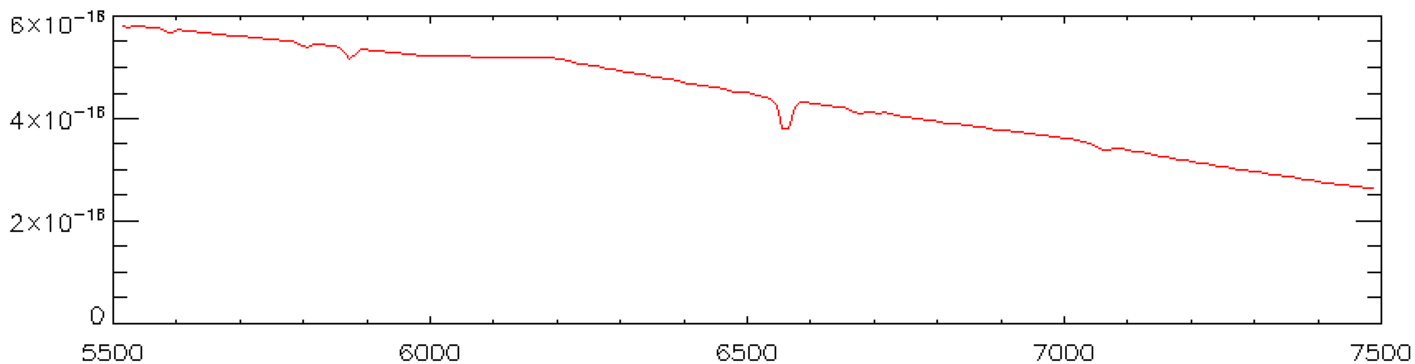
Velocity dispersion
Euler angles for line-of-sight
Signal/Noise ratio for the faintest star

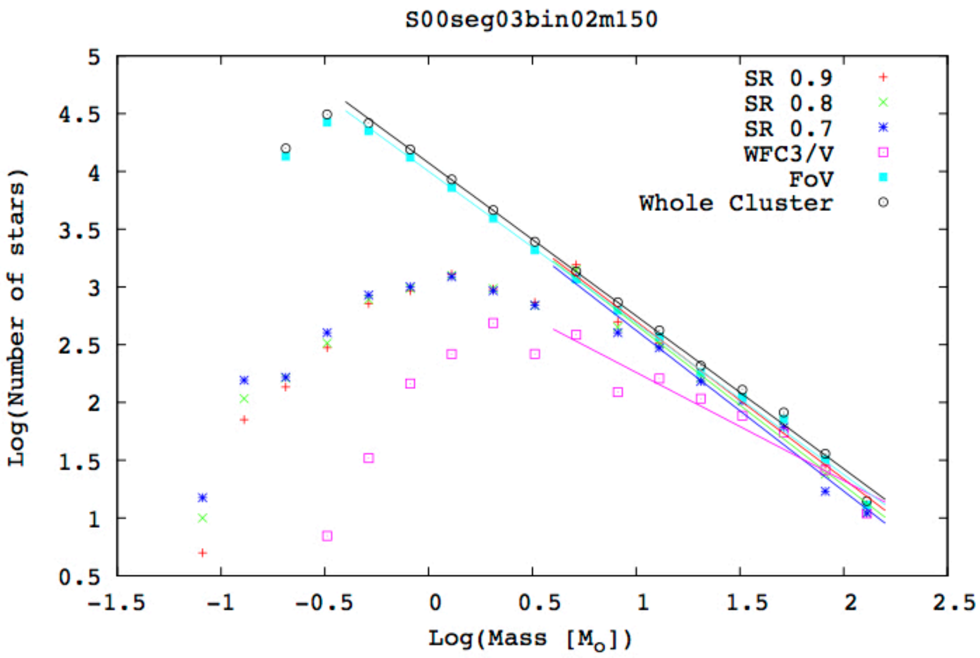


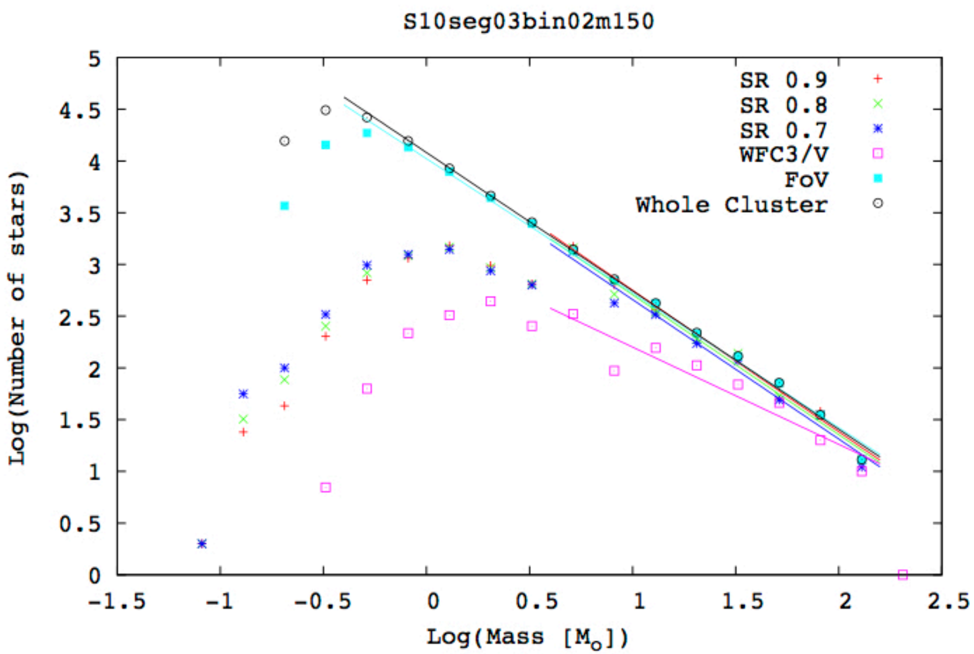
***_cube_spectra.fits** : 3D cube, X-Y is the position of stellar sources, z is flux in different wavelengths

Gaia-G filter
R=700

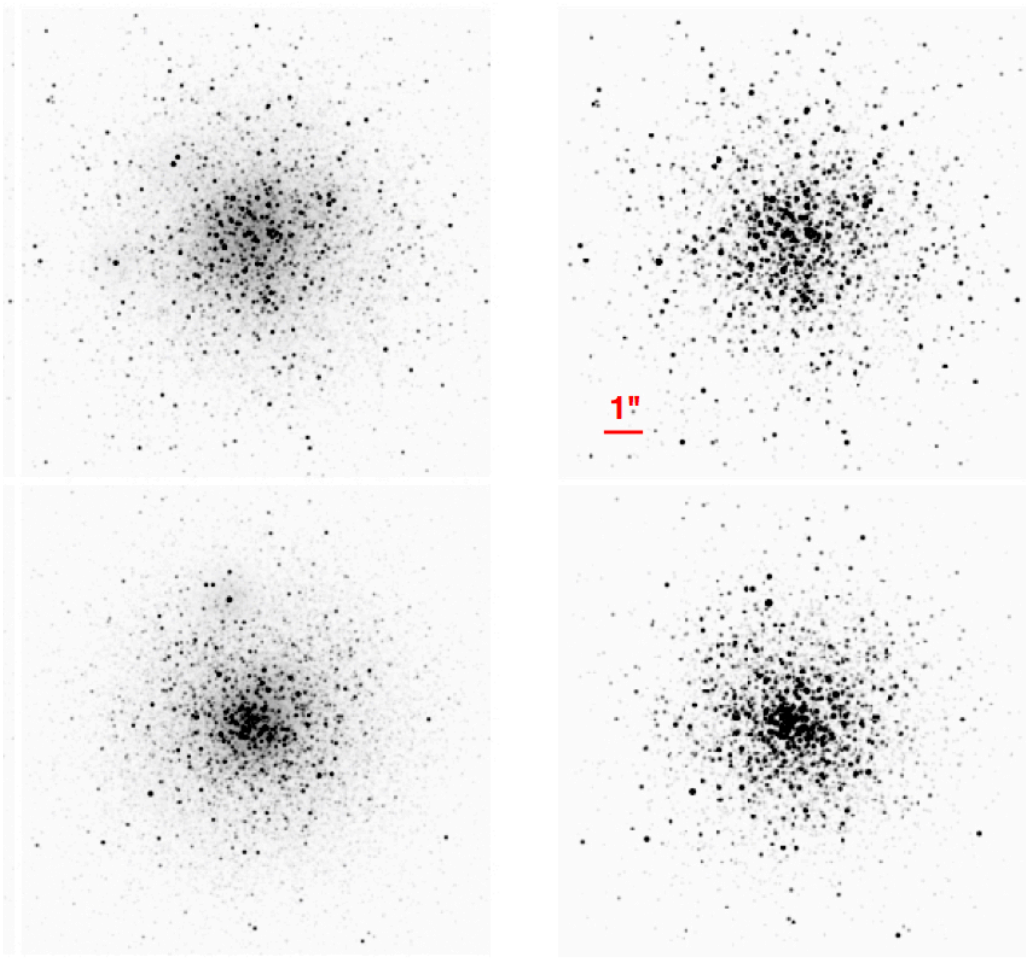








SR 0.9 **HST/WFC3/F555W**

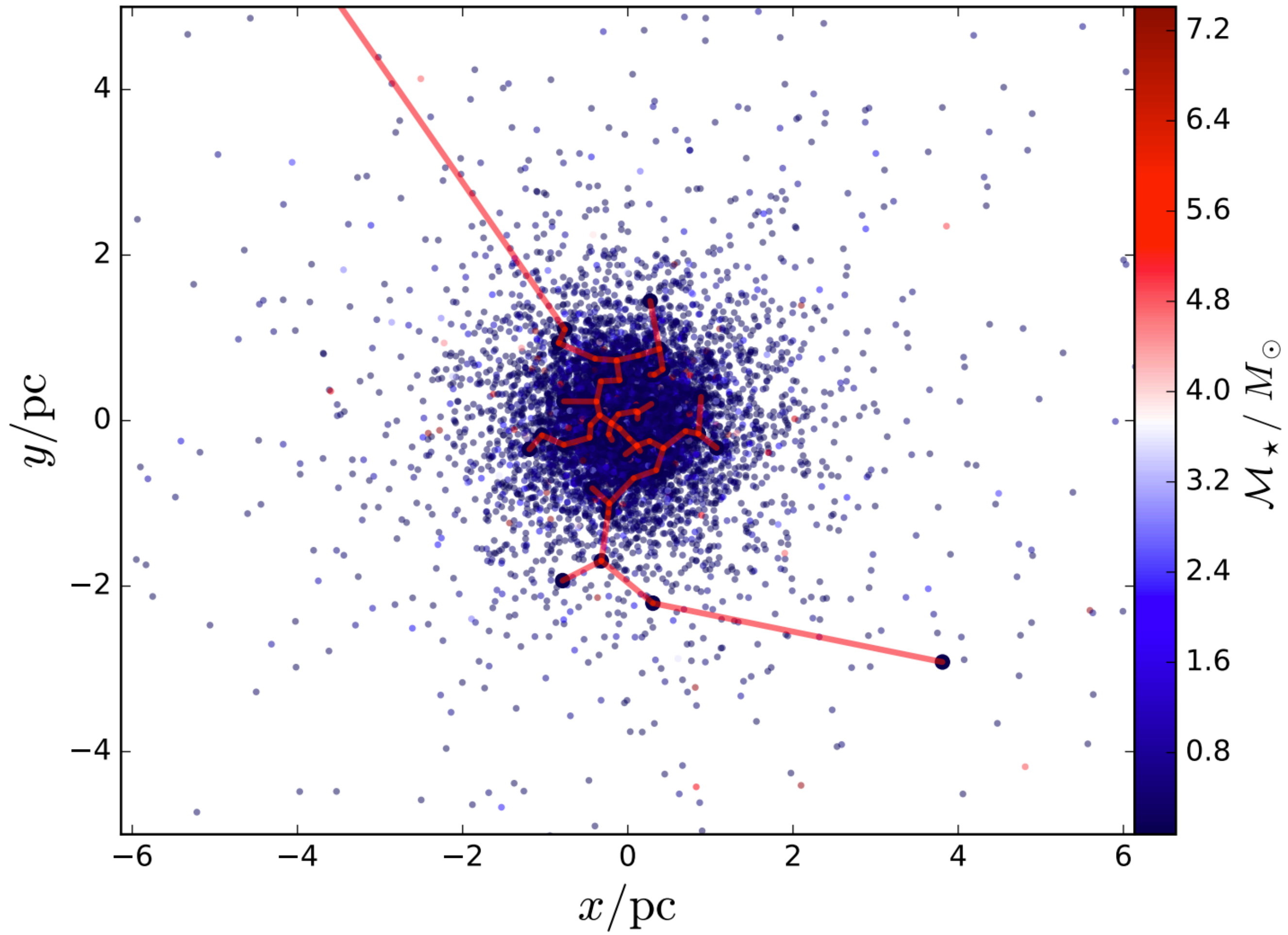


MF slope

K~1.38

V~ 0.93

Minimum Spanning Tree



[Yu et al. 2017]

$$\Lambda_{\mathrm{MSR}} = \frac{\langle l_{\mathrm{norm}} \rangle}{l_{\mathrm{massive}}} \pm \frac{\sigma_{\mathrm{norm}}}{l_{\mathrm{massive}}}$$

Λ_{MSR} **= 1.0: No-segregation**

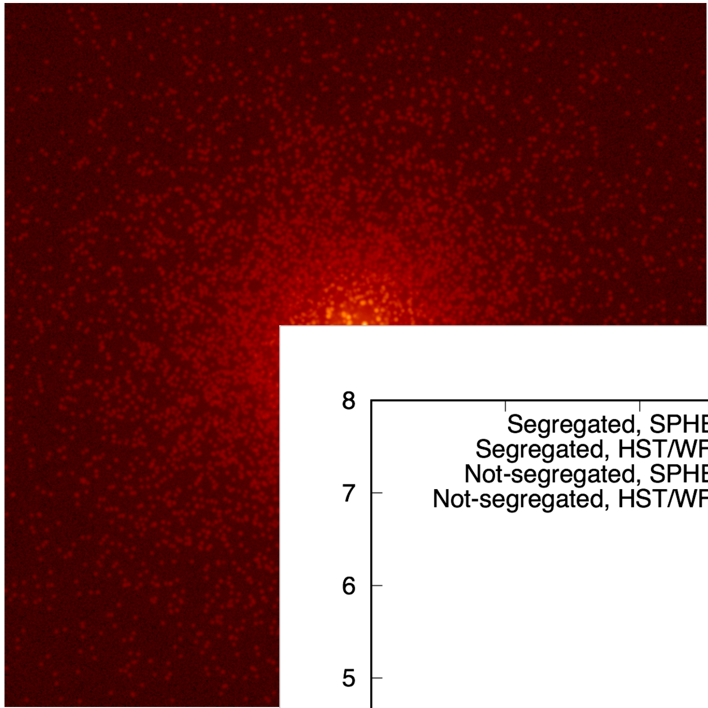
Λ_{MSR} **> 1.0 : Segregated**

[Allison et al. 2009]

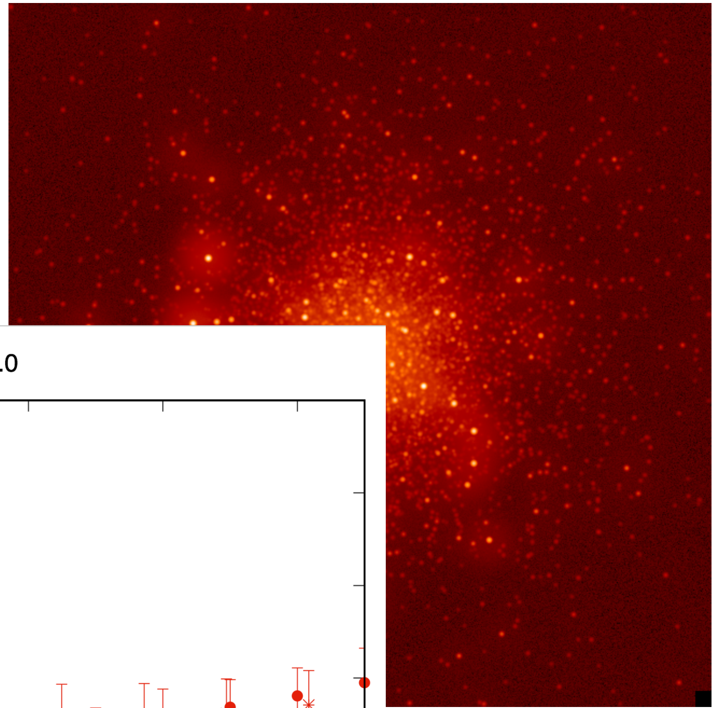
Sensitive parameters in MST method

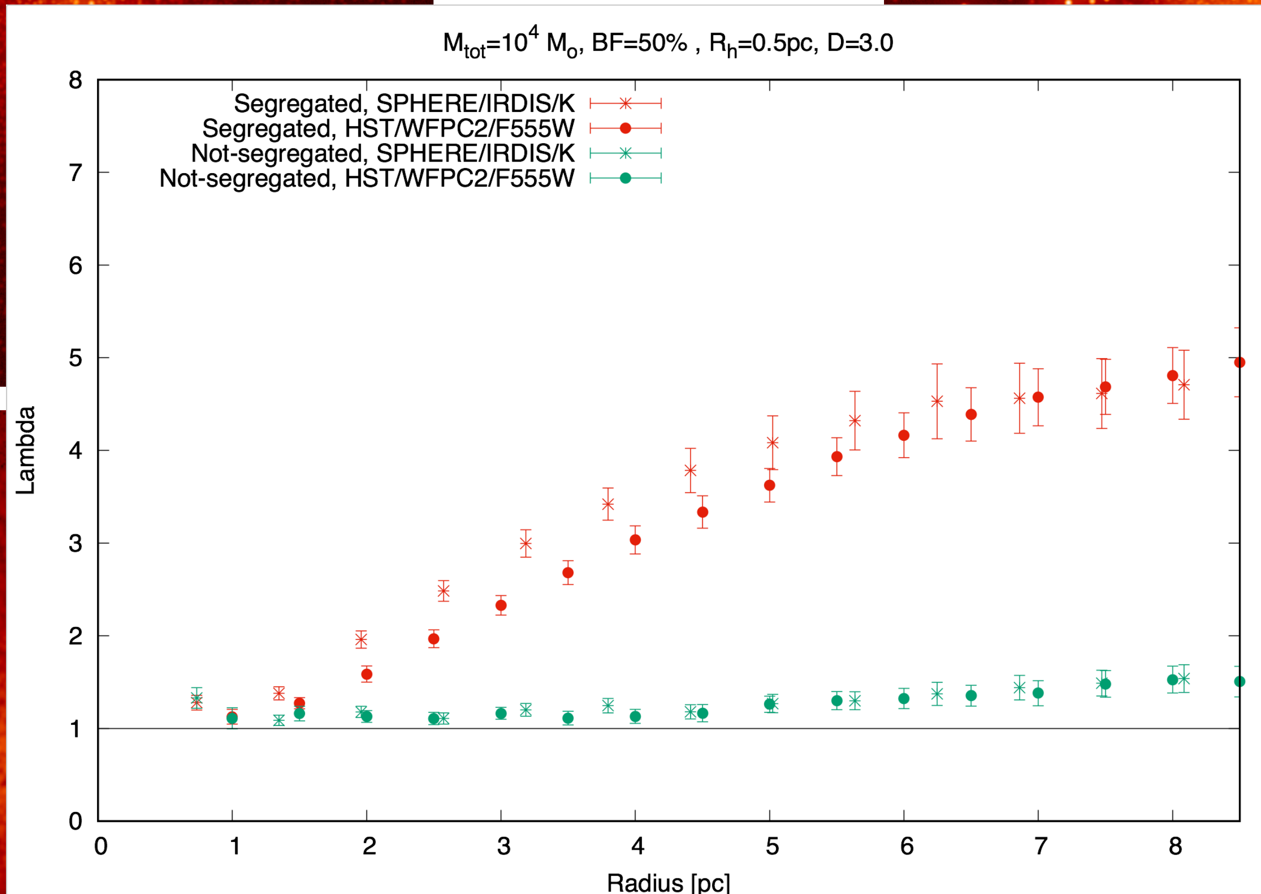
- Number of selected massive stars
- Low-mass limit
- Field of View (radius)

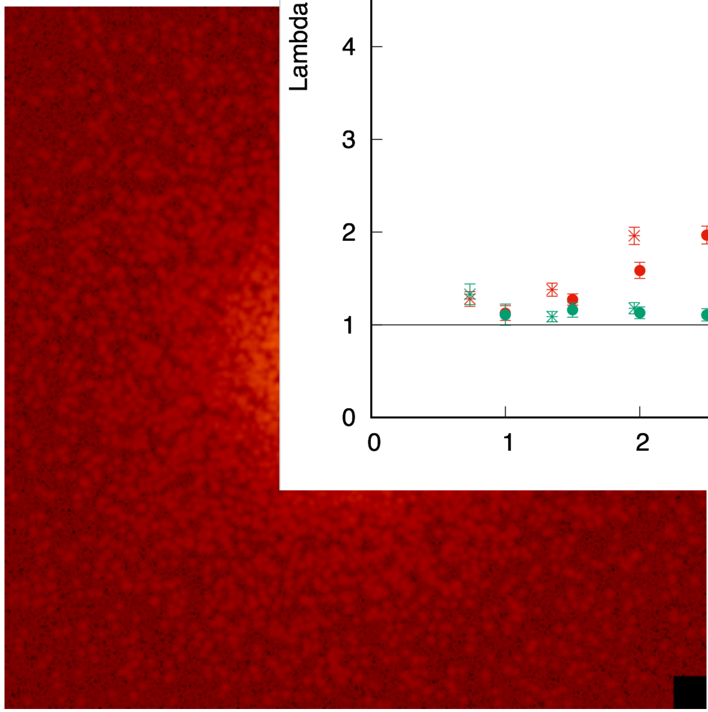
- Approximate mass estimation
- Binary fraction



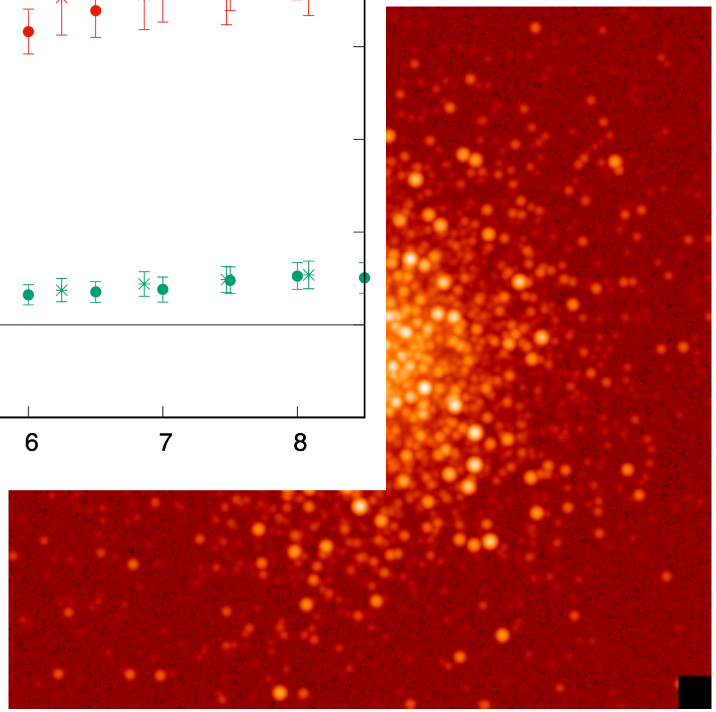
FoV: 16”x16”
VLT/SPHERE/K
SR=0.75
Seeing=0.8”

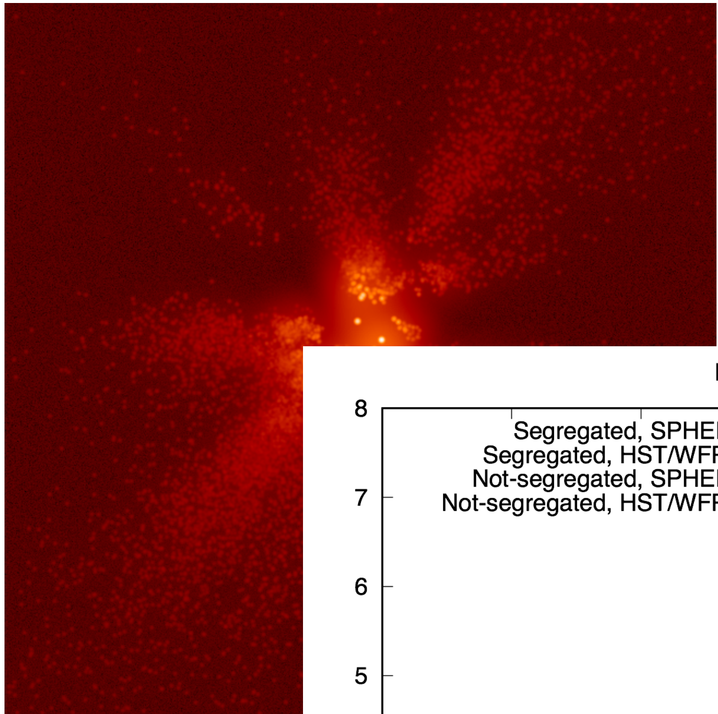




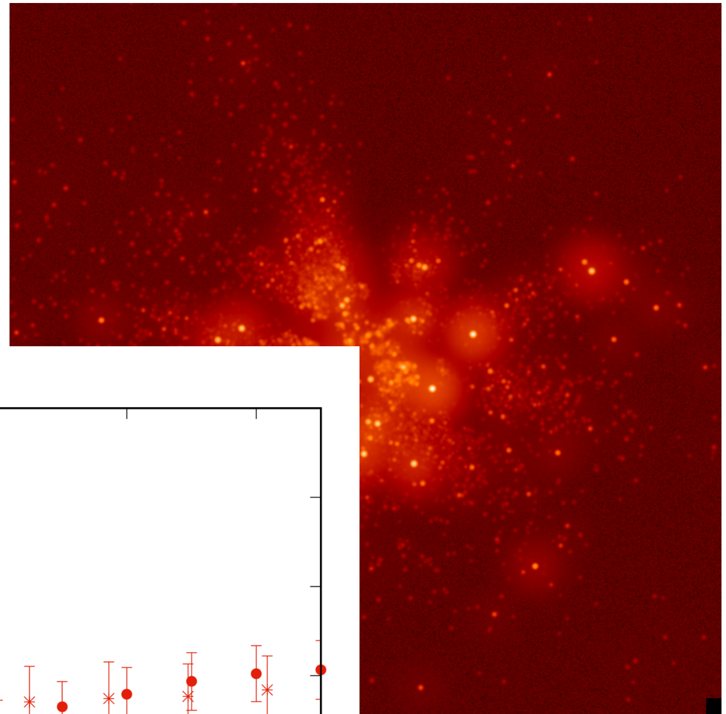


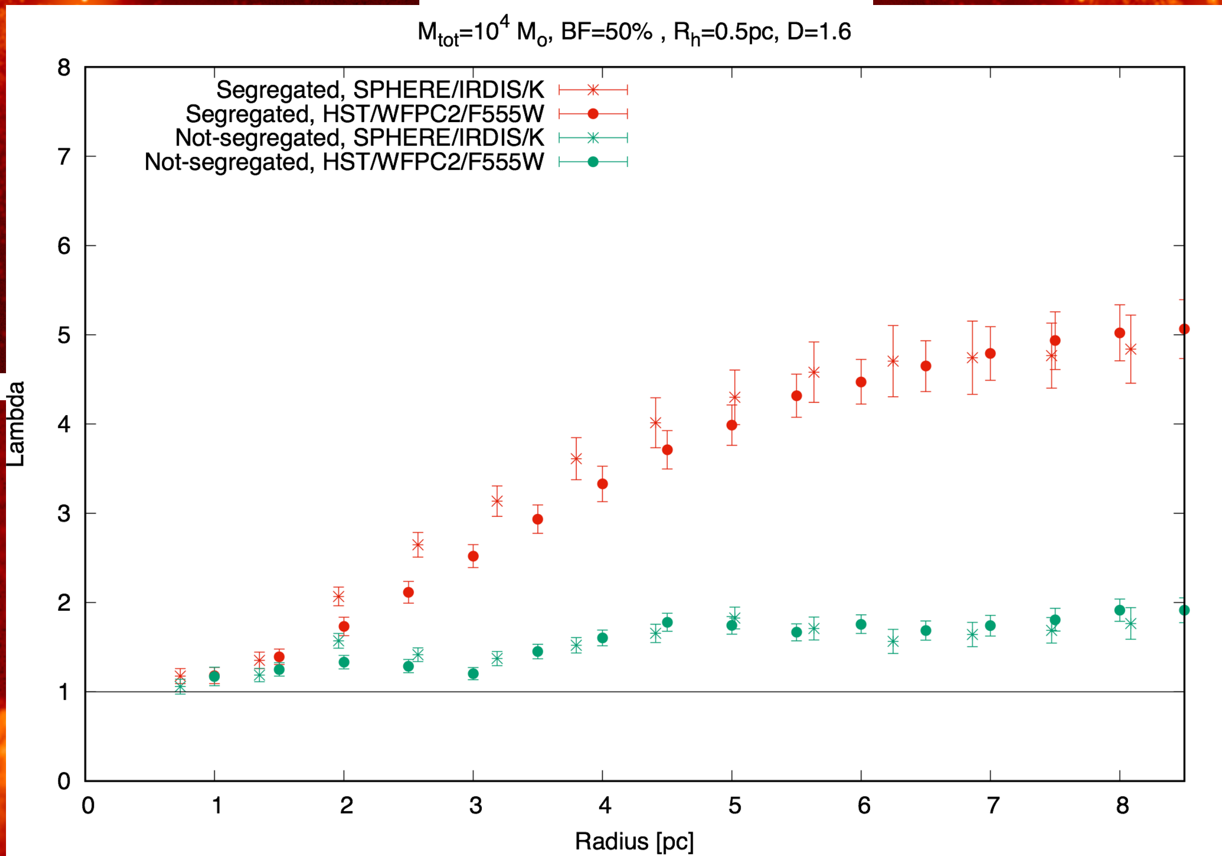
FoV: 16”x16”
HST/WFPC2/F555W

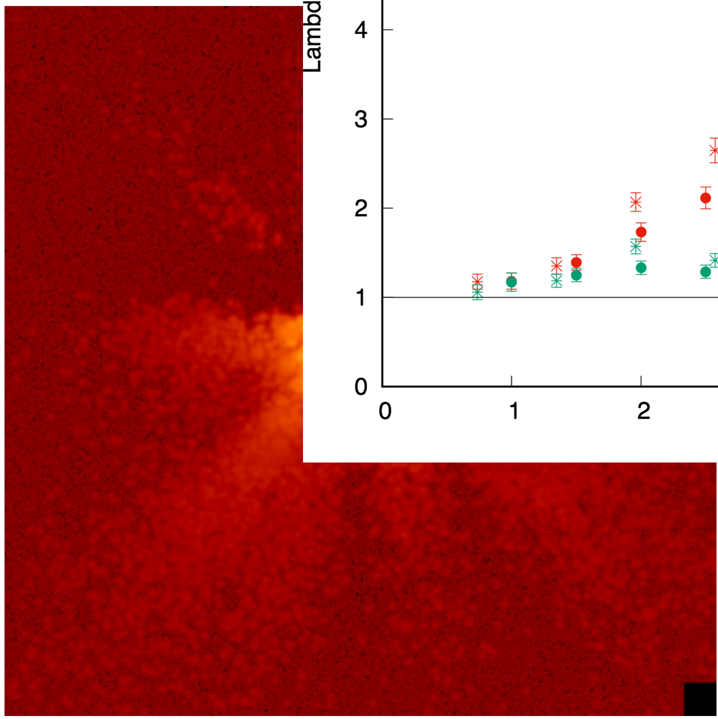


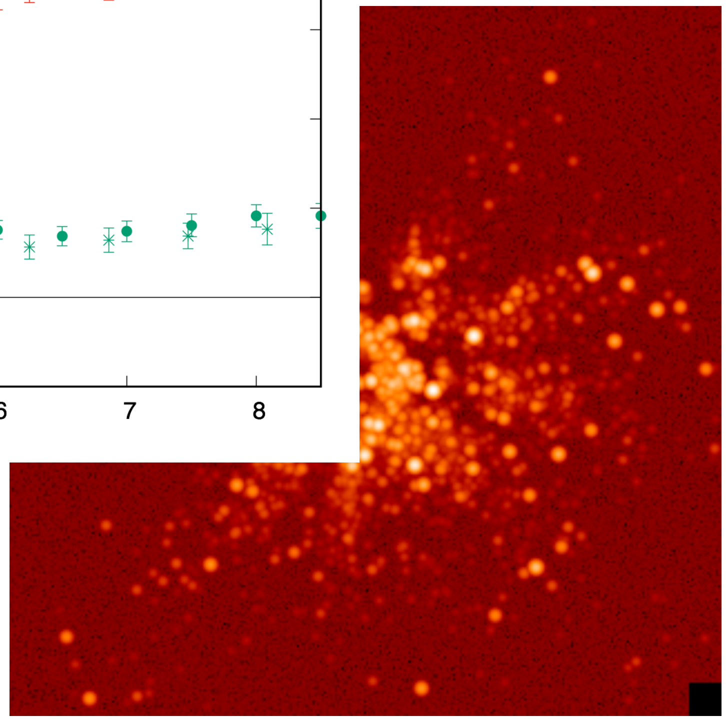


FoV: 16”x16”
VLT/SPHERE/K
SR=0.75
Seeing=0.8”









FoV: 16”x16”
HST/WFPC2/F555W

Summary and conclusion

- MF is sensitive to the resolution of the observational instrument
  - Observers need to compare the data with different resolution
  - We always need higher angular resolution data with better contrast
- Observed mass segregation in the core of NGC3603 probably is an observational confusion
- MST method can detect mass-segregation in the simulated data

Ongoing projects

- Evolution of star clusters with gas+stars
- Sets of Nbody simulations with different initial parameters:
  - M, r, Q, D, segregation, binary-fraction
- Creating synthetic observational data from these simulations
- Testing SFM tools on the synthetic observation data:
  - Sub-clustering (INDICATE in 2D)
  - Cluster's structure
  - Mass segregation using MST

Thanks for your attention!