Studying the stellar populations in the fuzzy cores of young massive clusters

Zeinab Khorrami

P. Clark (Cardiff University), F. Vakili (Observatoire de la Cote d'Azur),
T. Lanz (Observatoire de la Cote d'Azur)

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Cardiff University

Young Massive clusters

Dense aggregate of newly formed stars with lots of difficulties!

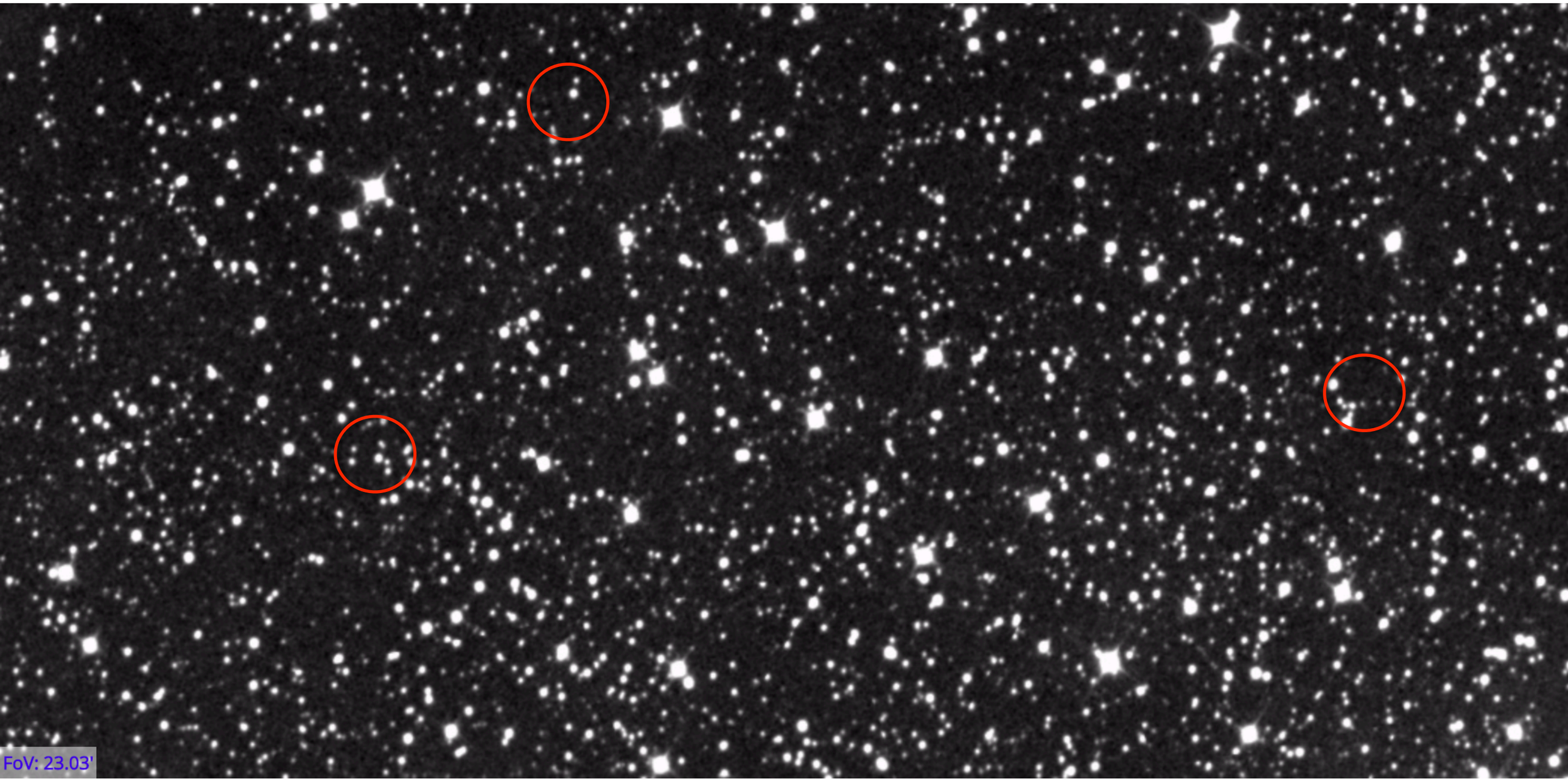
- Immersed in gas/dust: High (inhomogeneous) extinction
  Observations in longer wavelength

- Most of them are not close enough: their individual members probably are not resolved
  High angular resolution observations

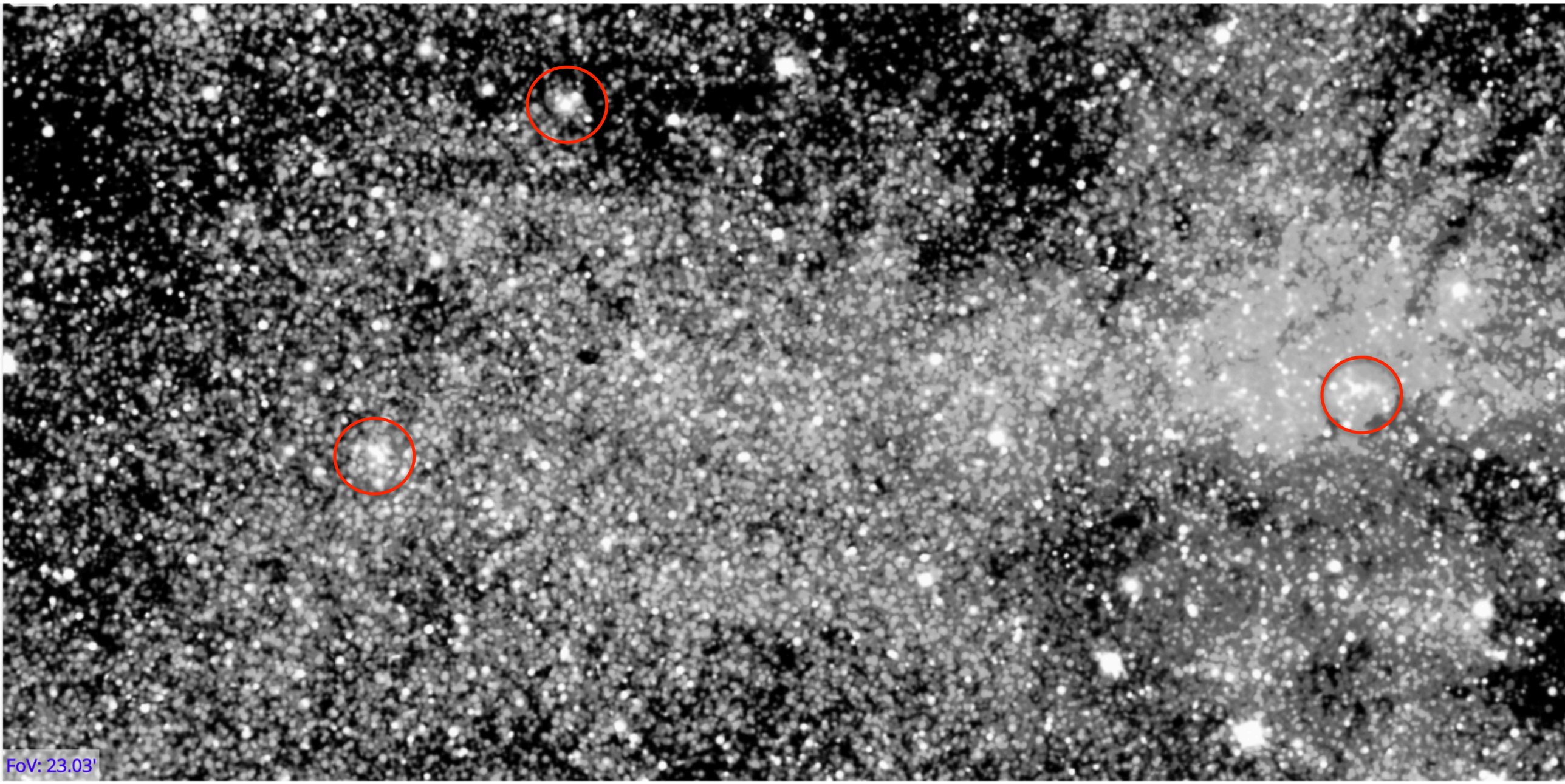
- Massive hot stars mask the faint low-mass stars.
  High contrast imaging

DSS2 Blue

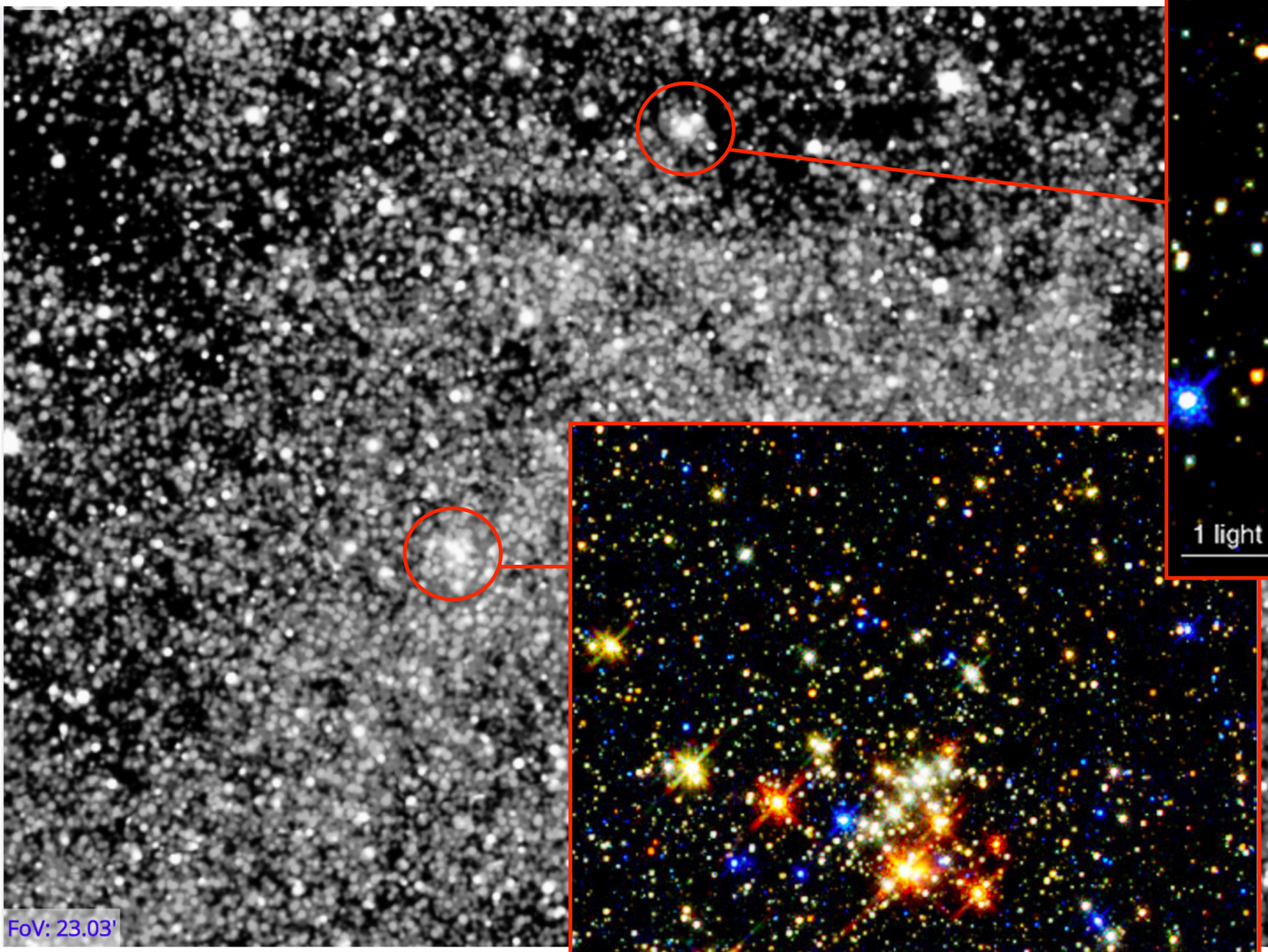
DSS2 Red



2MASS J,H,K



2MASS J,H,



Next step …

1. Proper evolutionary/atmosphere model

2. Estimating stellar masses, ages

3. Investigate physics of the newly formed cluster:

   - MF, density profile, Virial status, mass-segregation
   - Feeding cluster-formation simulations, gravitational-dynamical evolution
   - Filling the gap between cluster formation and evolution

Final step …

To compare simulations with observations we should use
synthetic observations

With **MYSO** feel free to

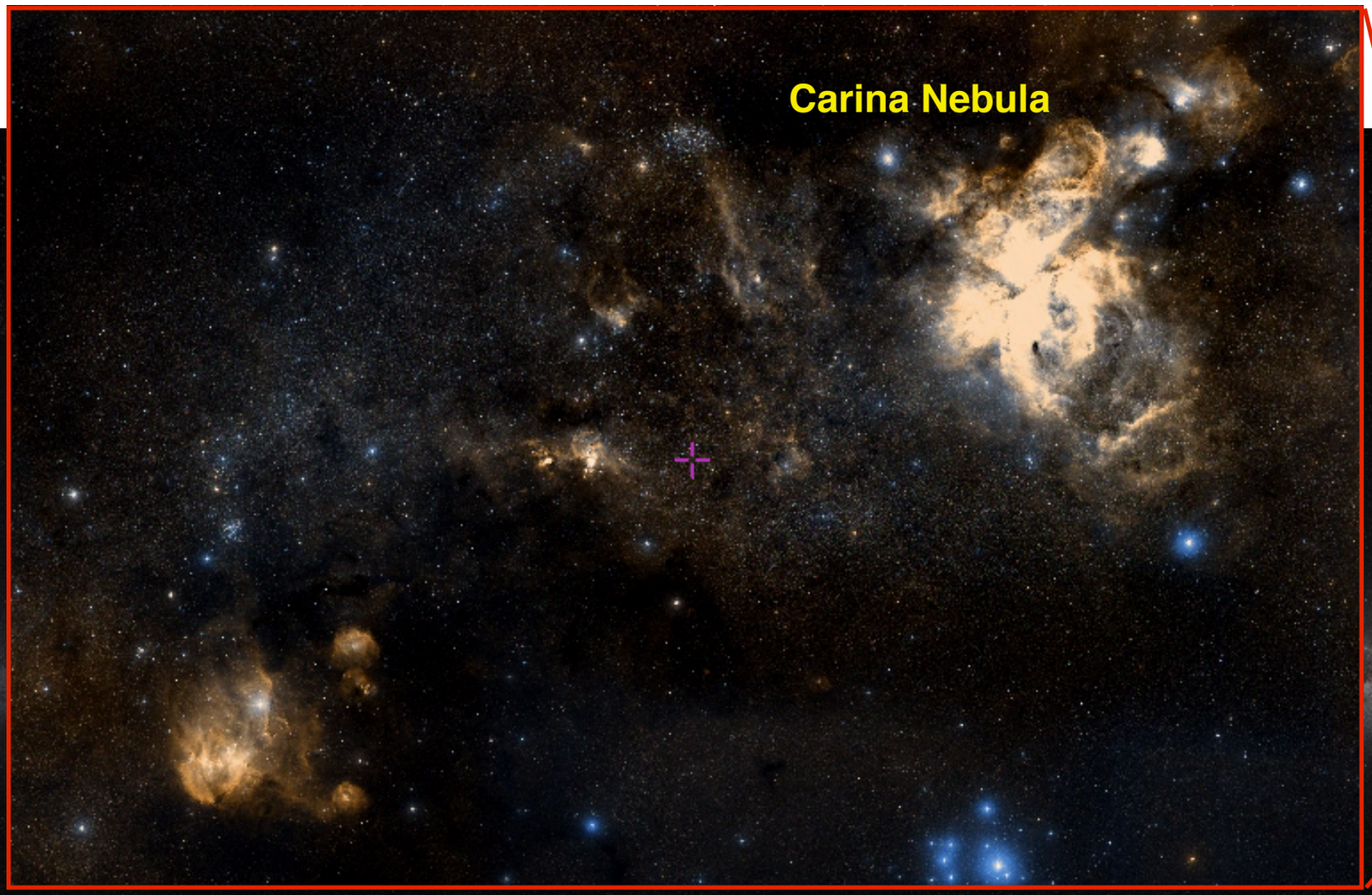
Make **Y**our **S**ynthetic **O**bservations!

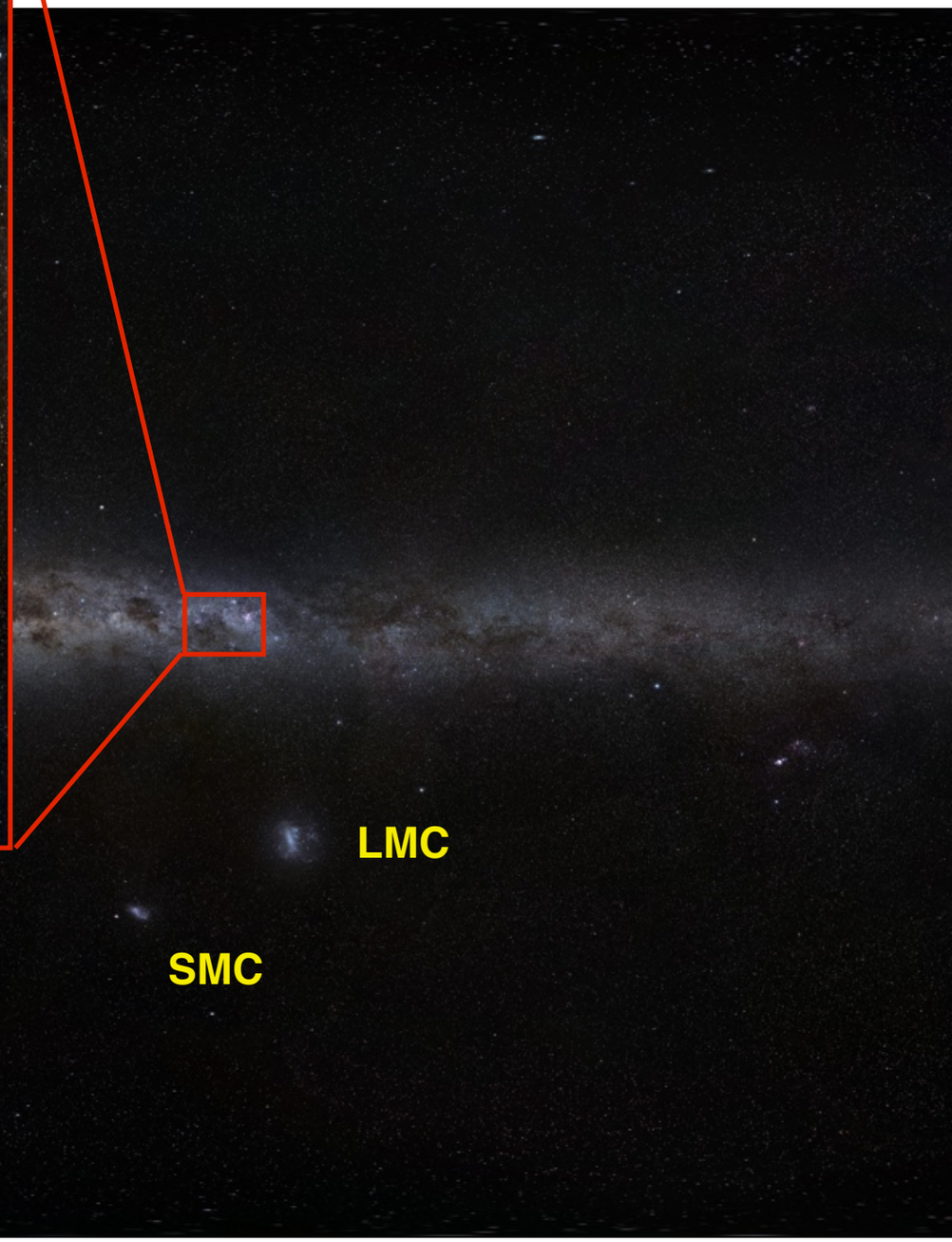
Two similar clusters (age and stellar population)

in different distances

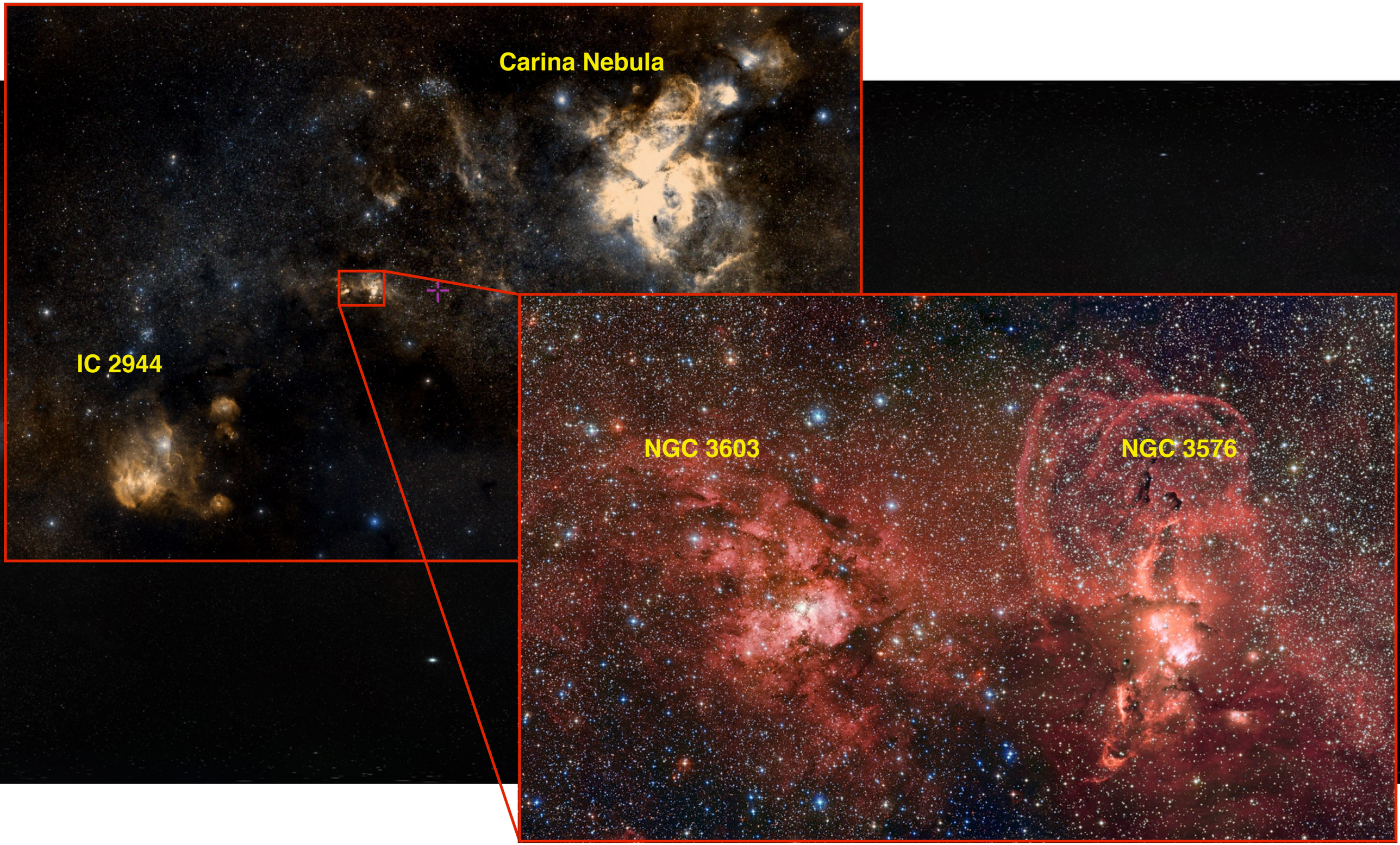
NGC 3603

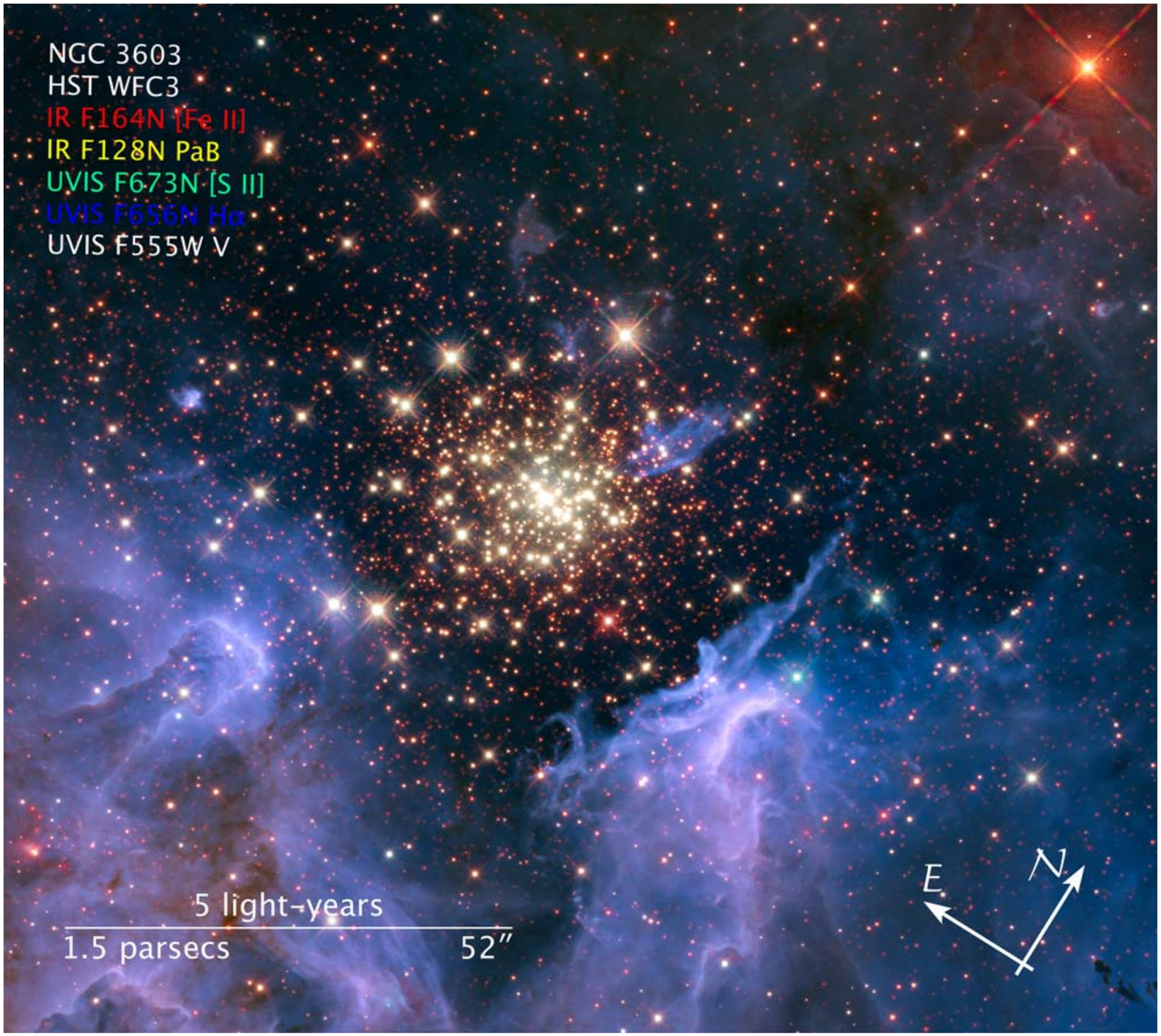
NGC 3603





NGC 3603





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

$$Age \sim 1 - 2 Myr$$

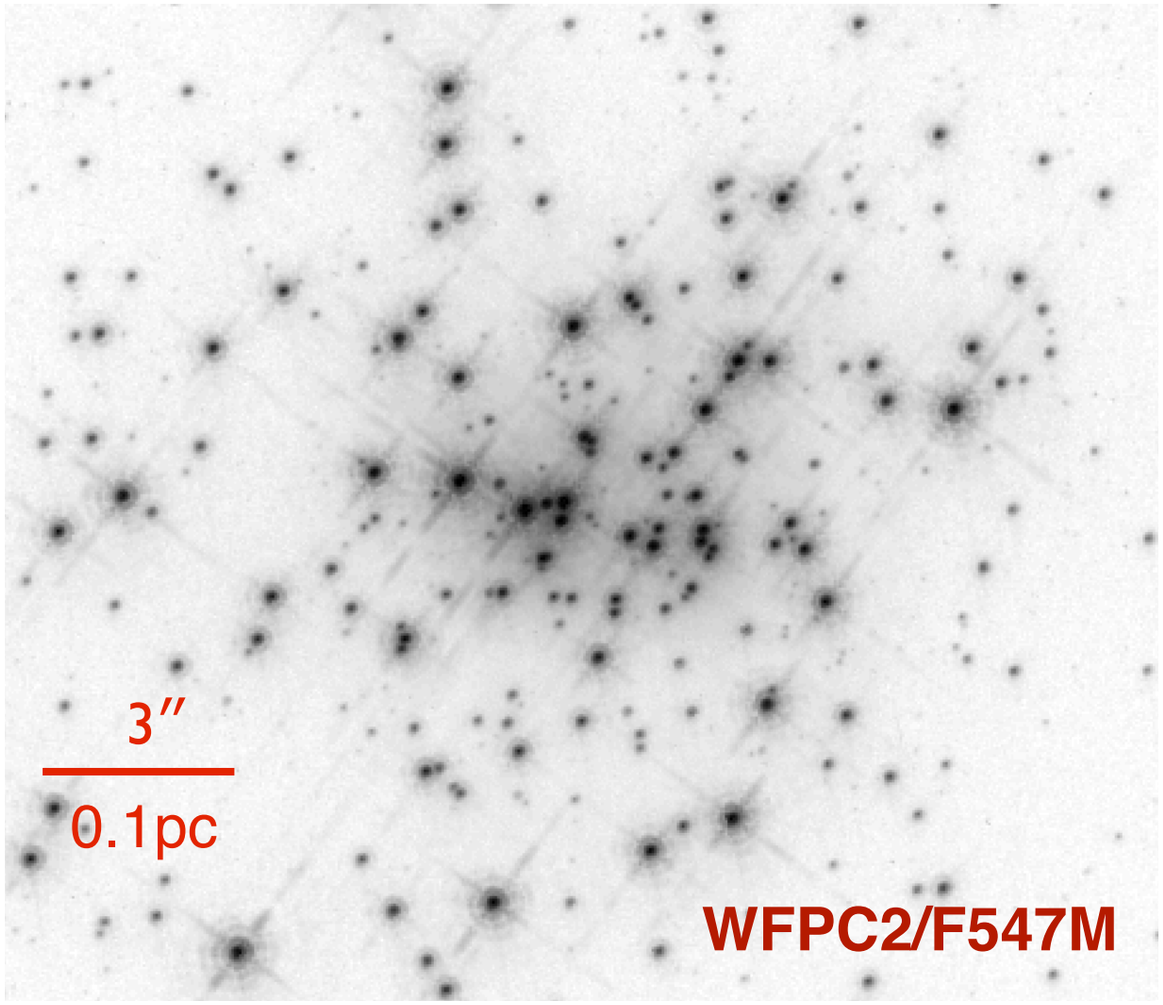
$$Dis \sim 6 - 7 Kpc$$

$$Constellation : Carina$$

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]

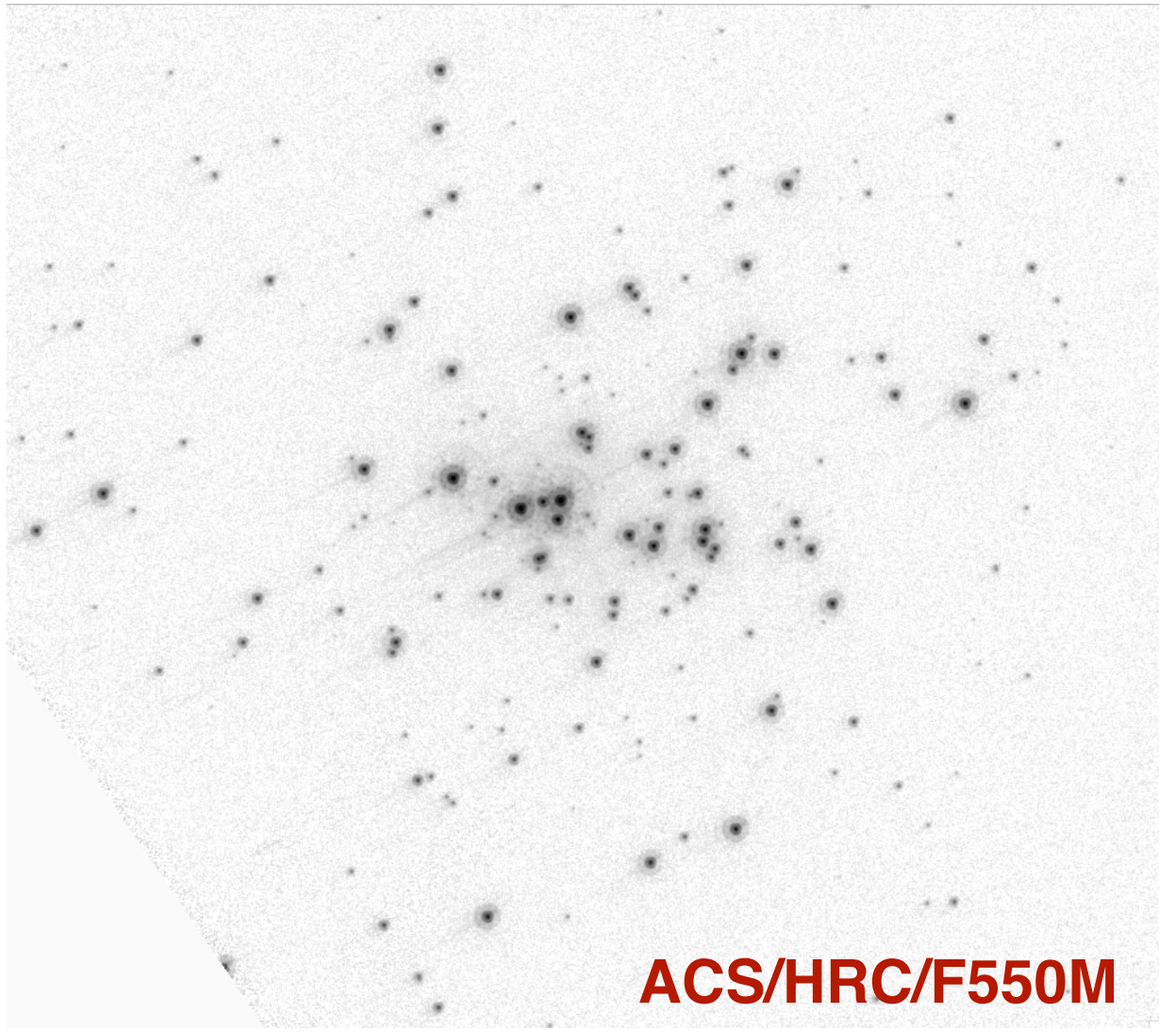
Different observations

Different MF slopes

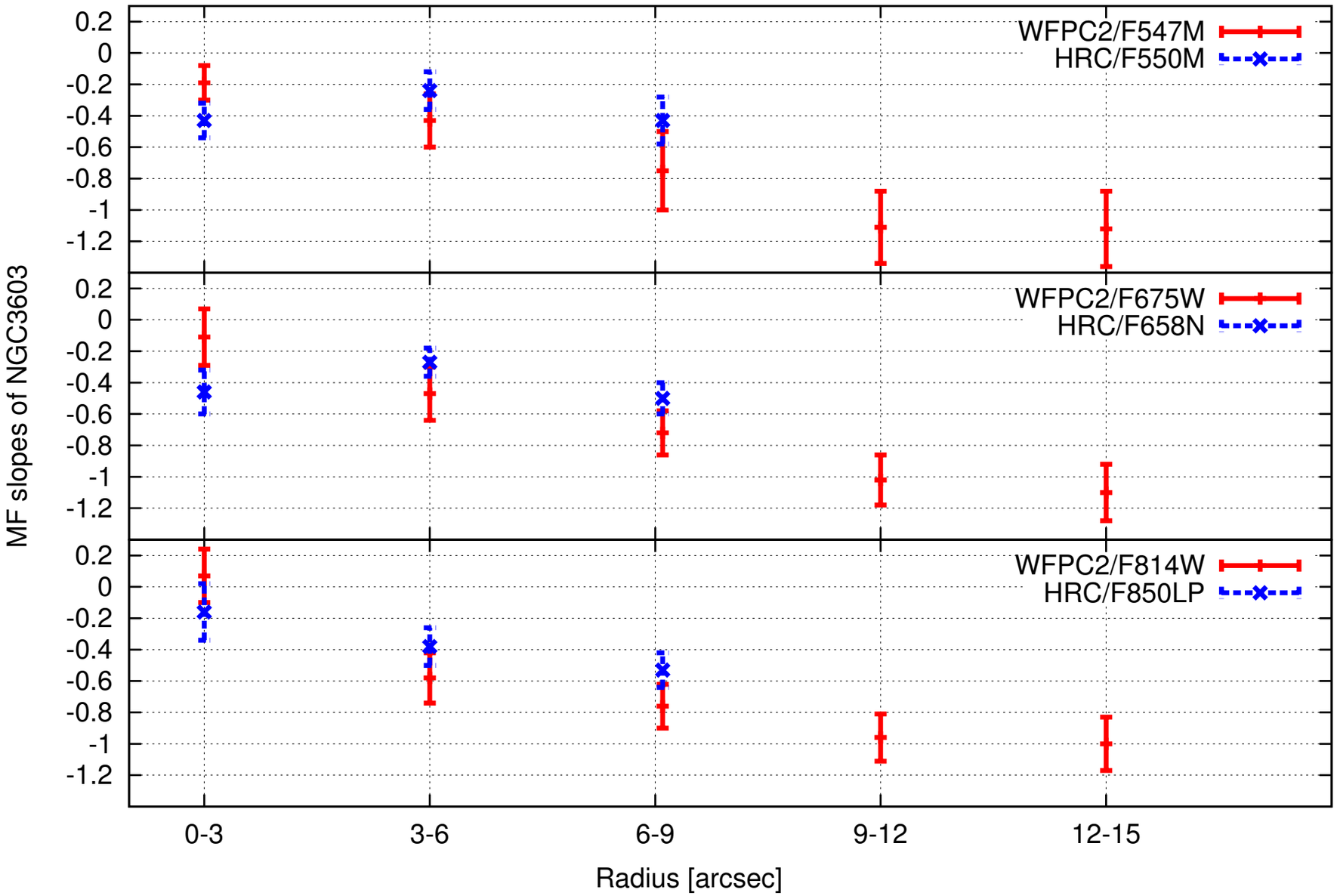


WFPC2
Filters: V,R,I
50mas/pix

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

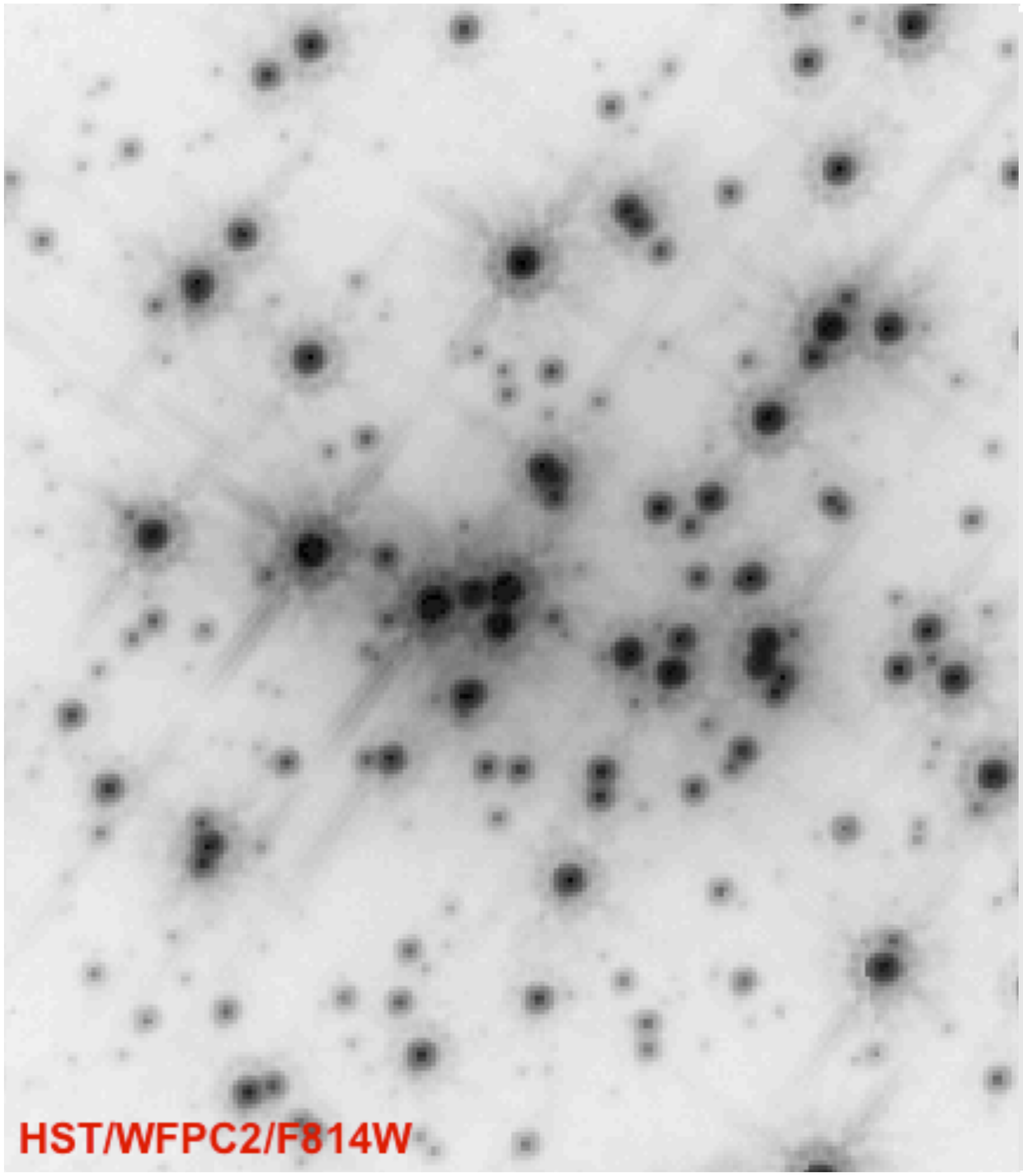


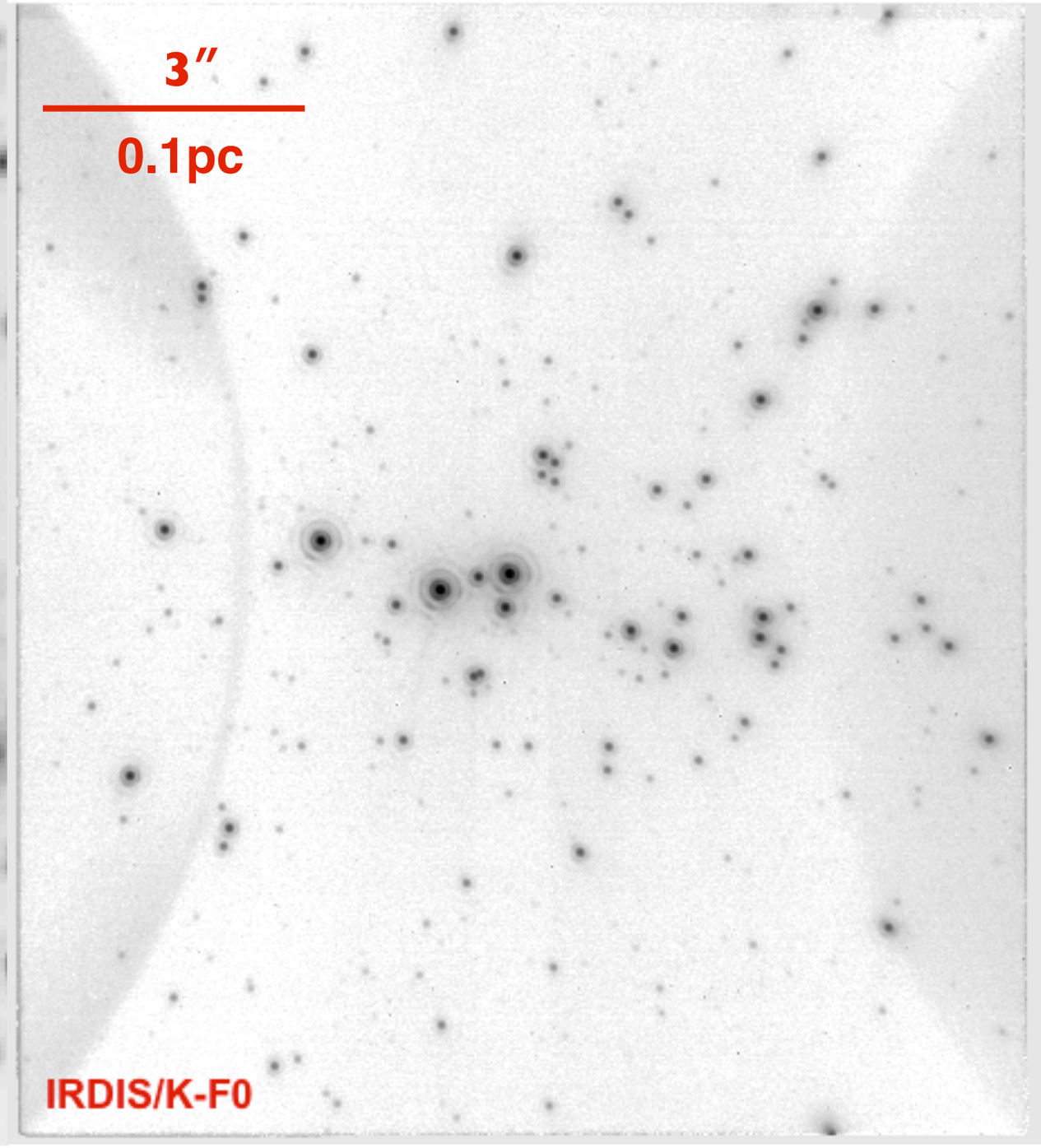
MF example: NGC3603



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

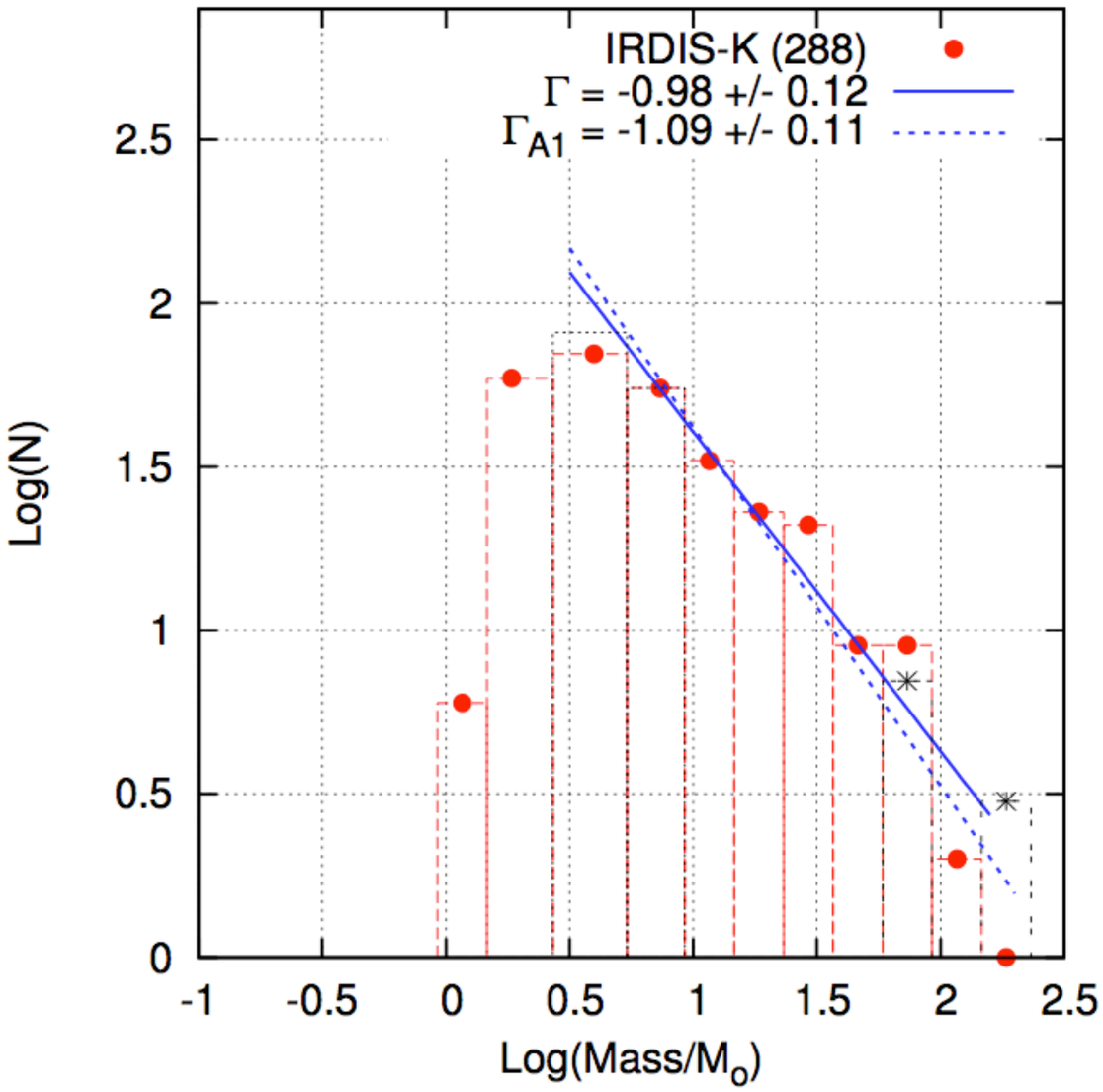
MF example: NGC3603

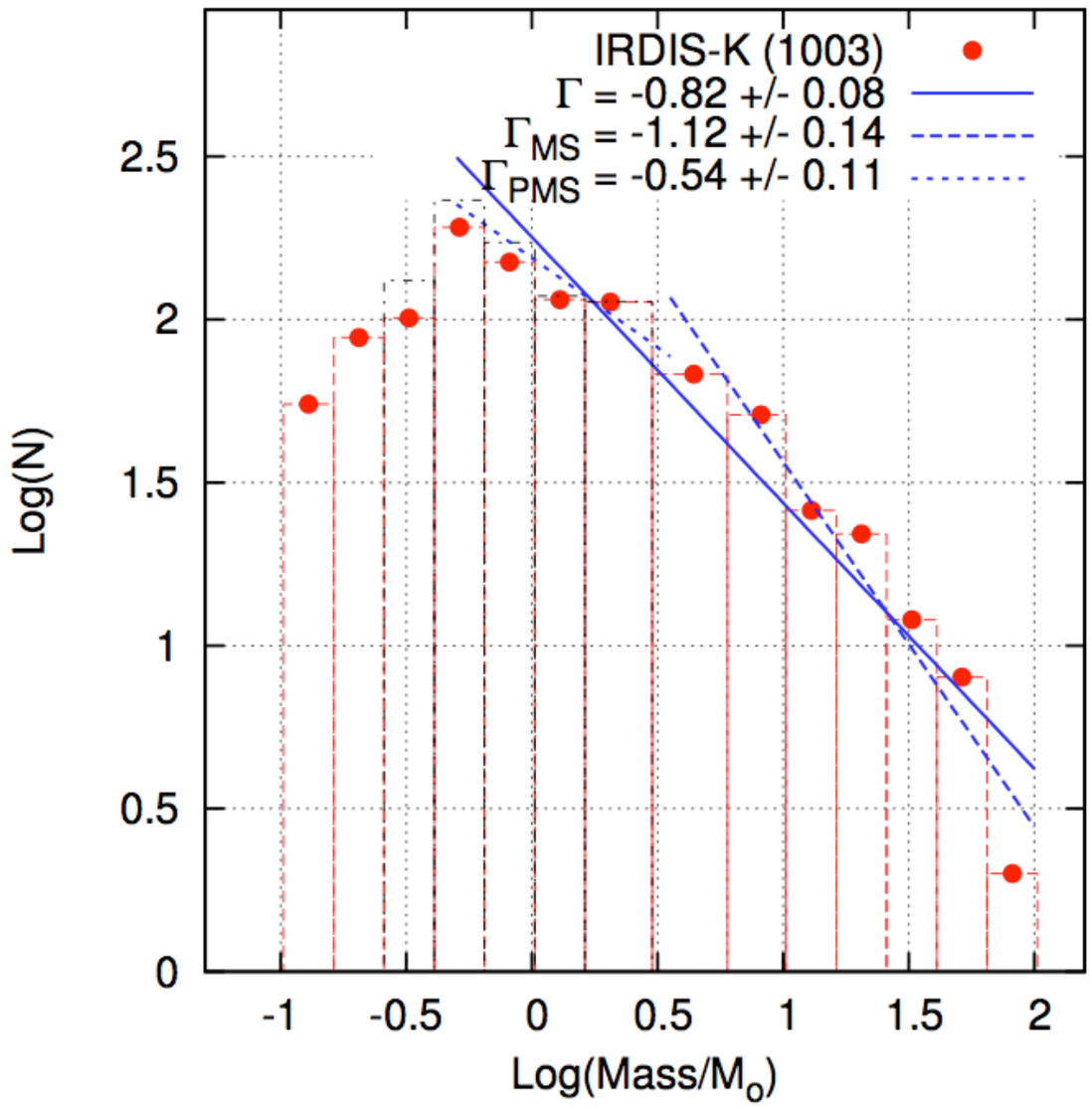




High angular and contrast images from VLT/SPHERE

MF example: NGC3603





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

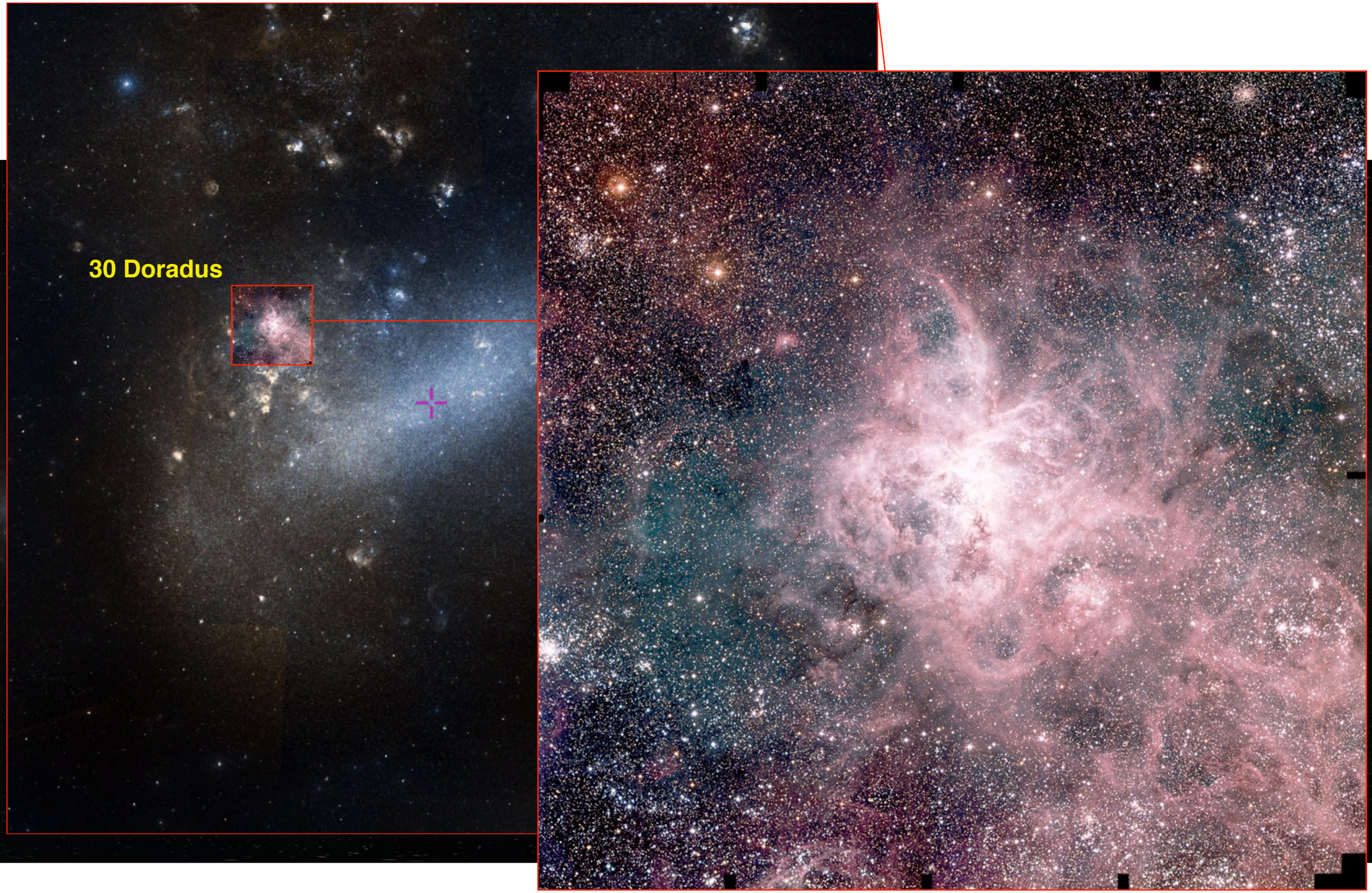
2) Both slopes are similar to the MF values found in previous works for the outer regions

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

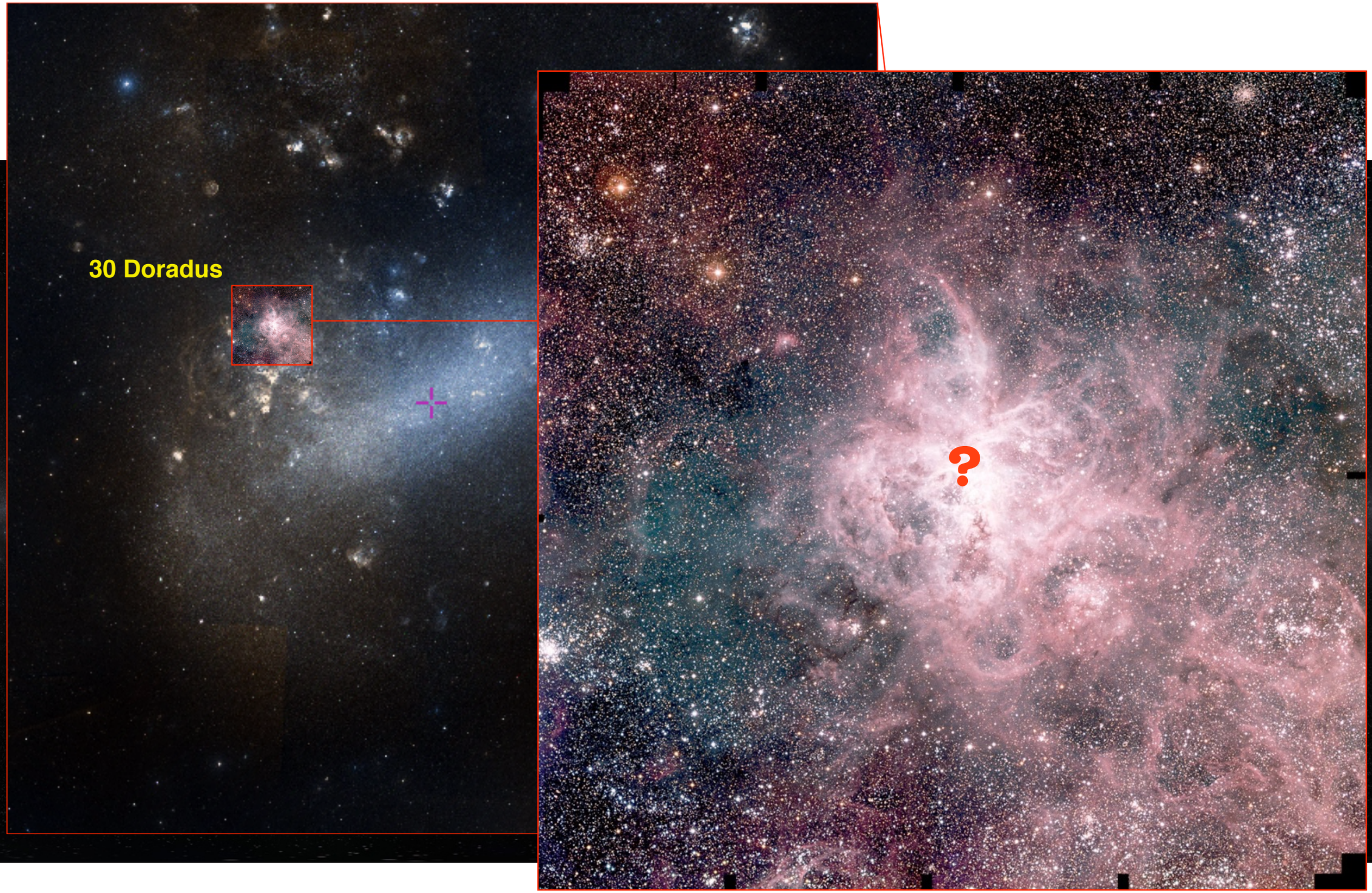
R136

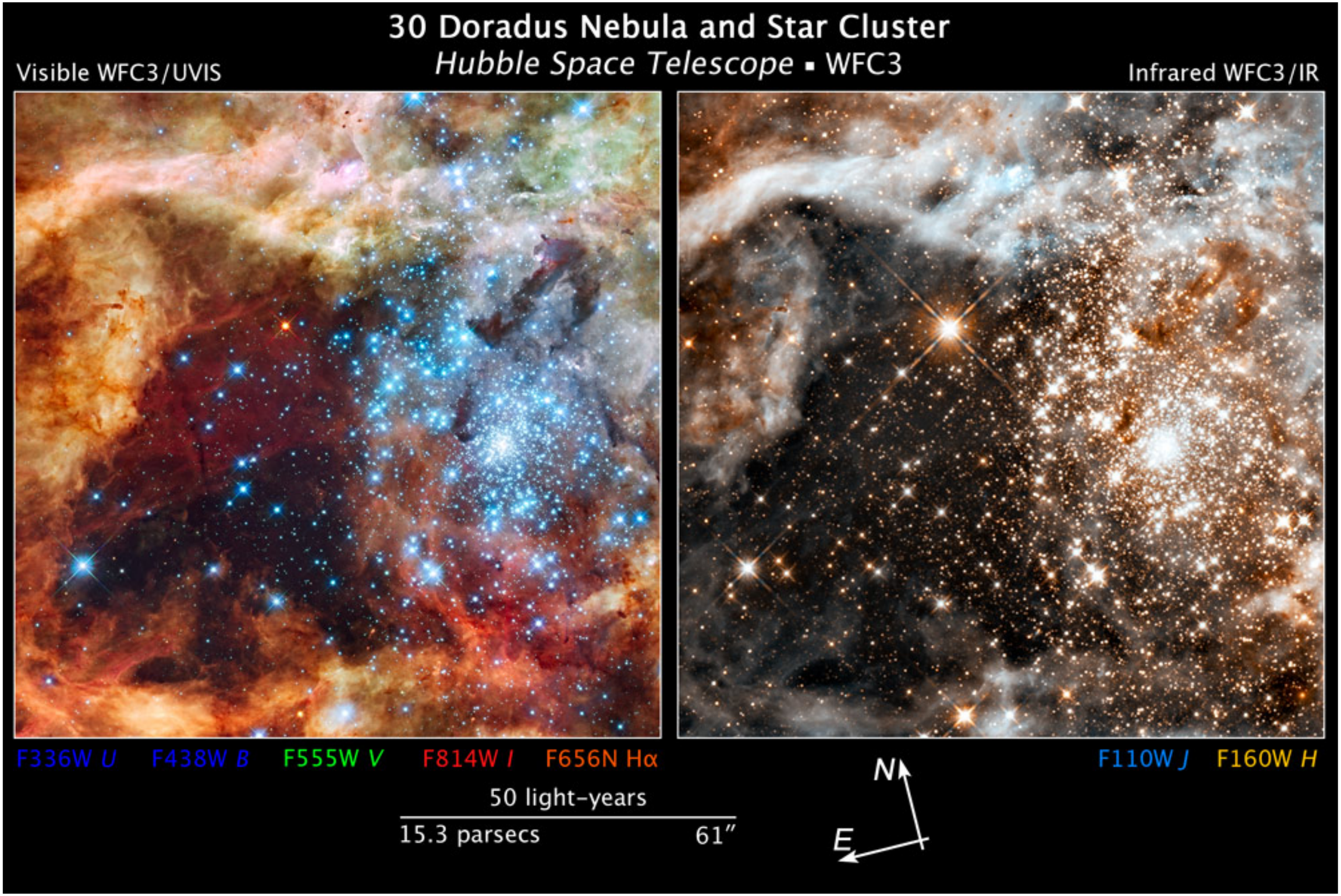
MF example: R136

MF example: R136



MF example: R136





$Dis \sim 50Kpc$

$Constellation : 30Doradus$

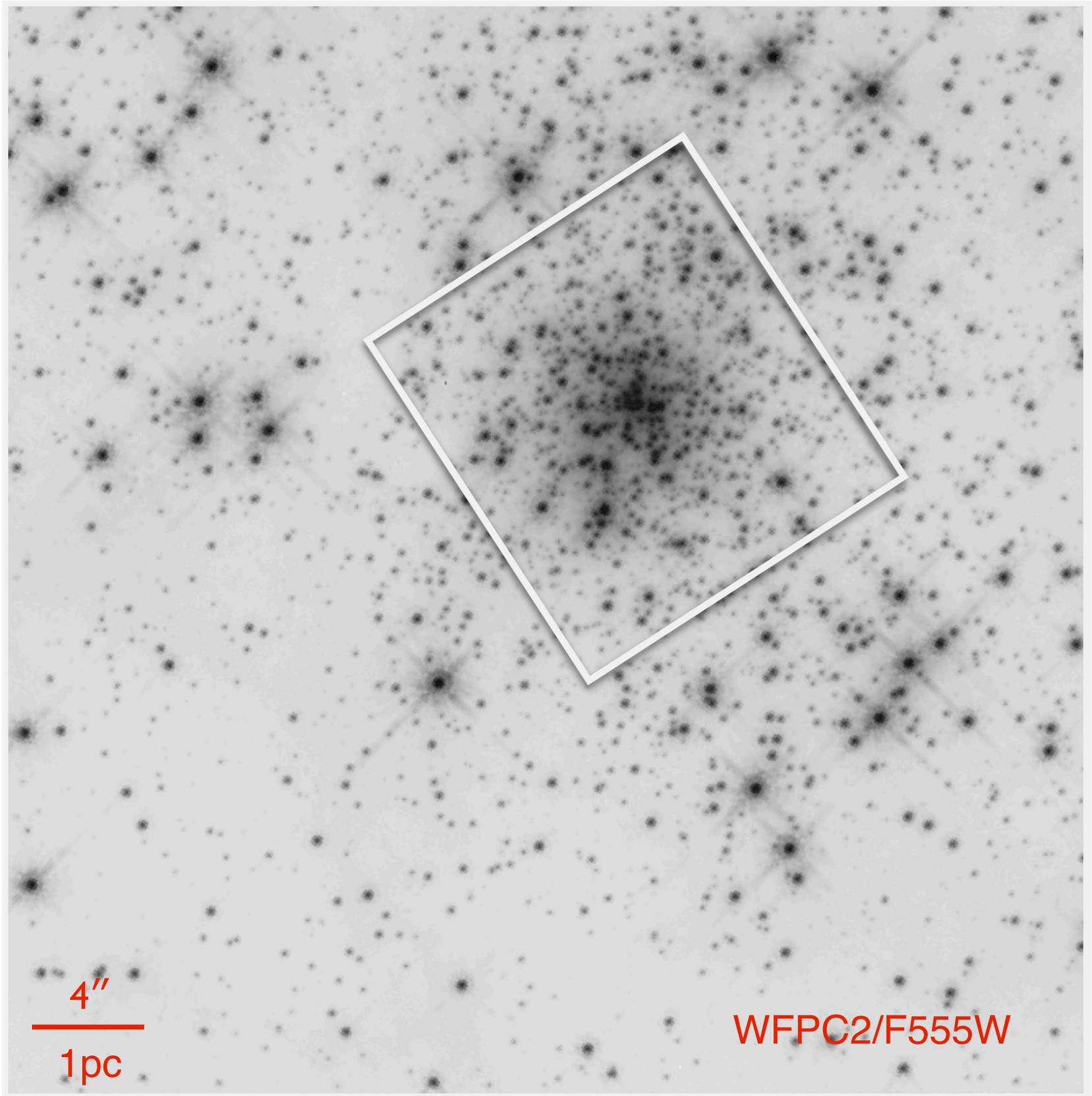
$M_{total} \sim 10^5 M_\odot$

$Age \sim 2 - 3Myr$

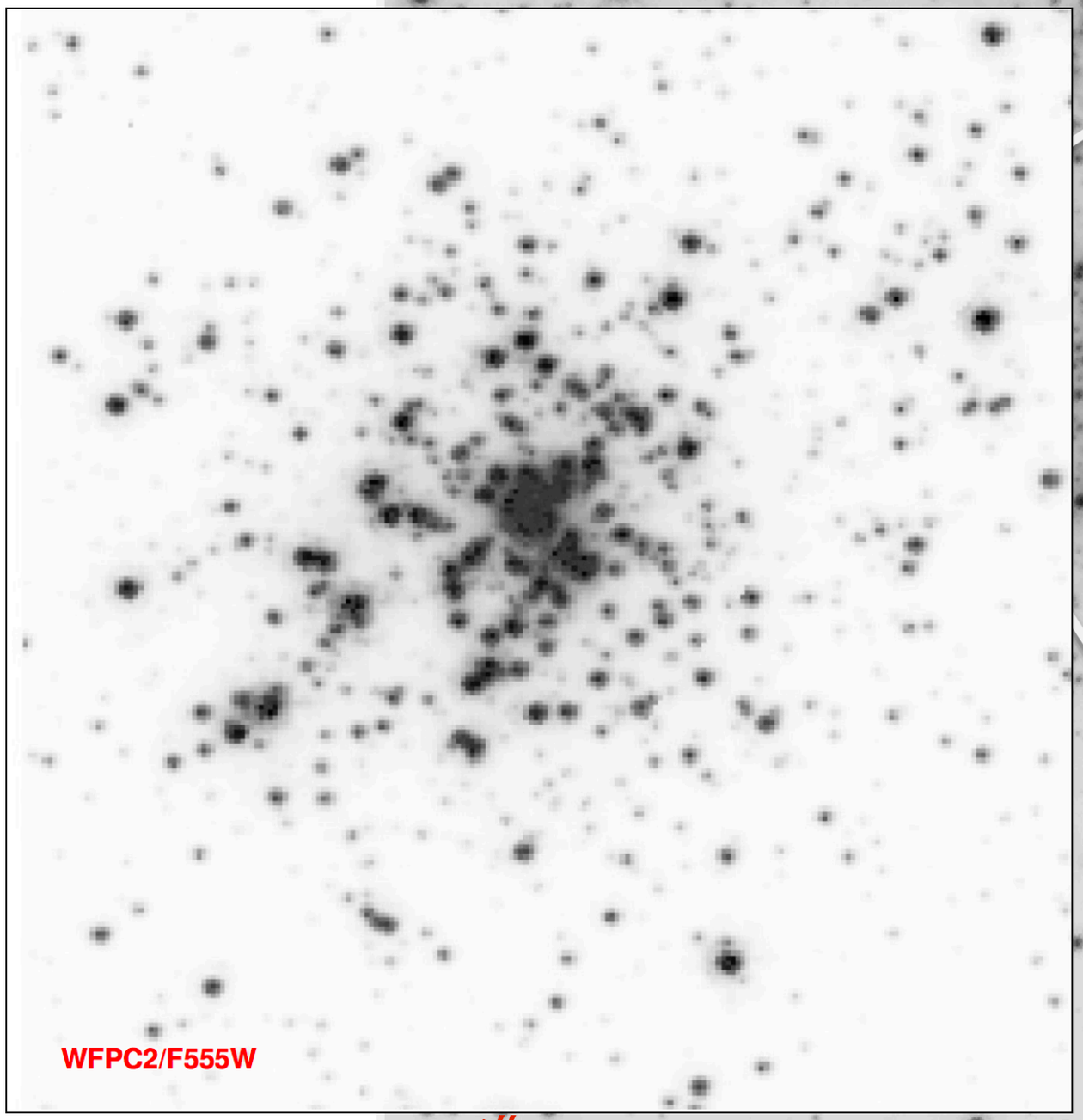
Mass function slopes for R 136 from previous analyses.

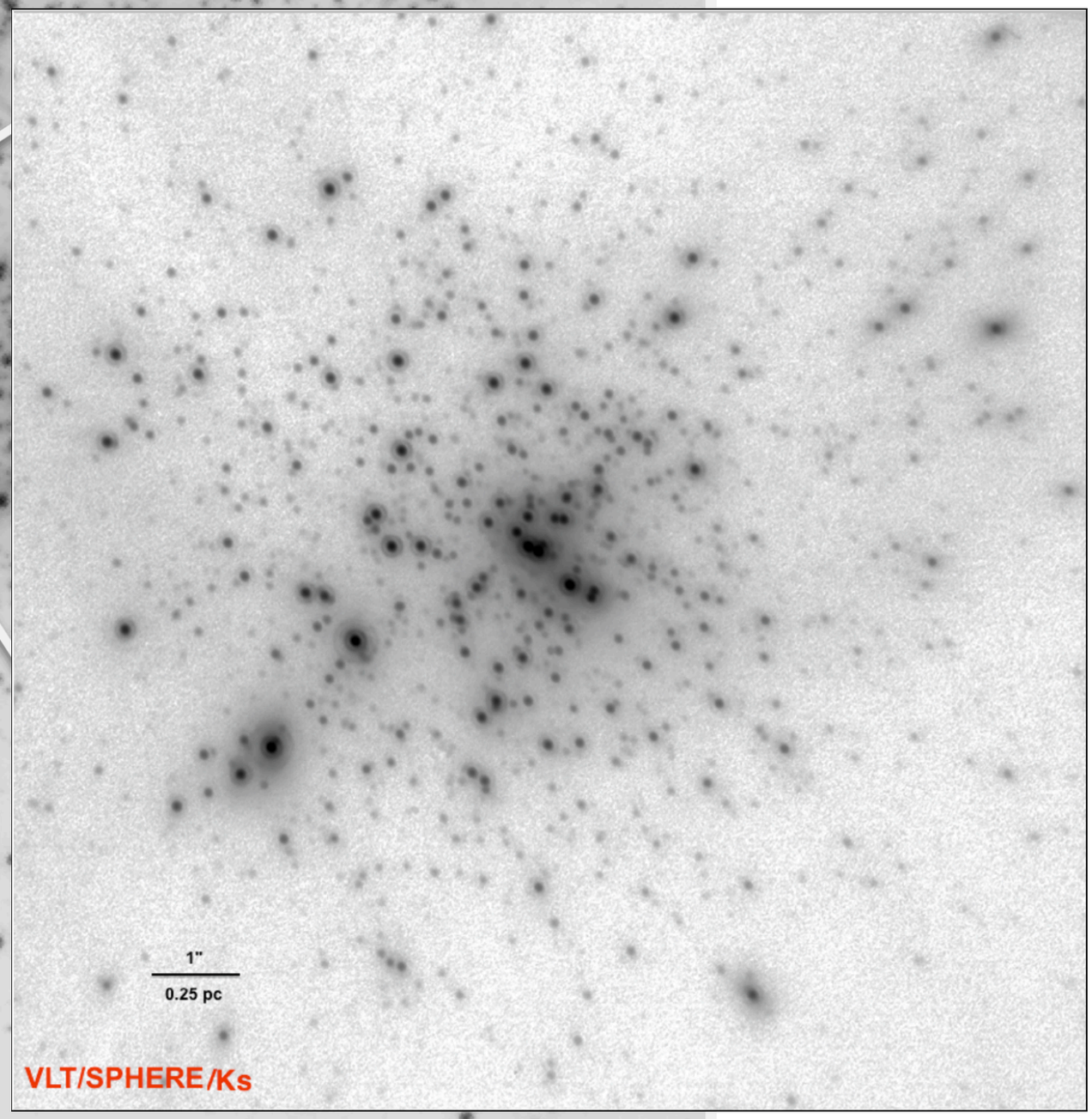
MF slope	Condition	Reference
−0.90	(20–70) $M_\odot$ $r < 3''.3$	Malumuth & Heap (1994)
−1.89	(20–70) $M_\odot$ $3''.3 < r < 17''.5$	Malumuth & Heap (1994)
-1.0 ± 0.1	(2.8–15) $M_\odot$ $2''.0 < r < 18''.8$	Hunter et al. (1996)
(−1.3)–(−1.4)	(15–120) $M_\odot$	Massey & Hunter (1998)
−1.59	$r < 1''.6$	Brandl et al. (1996)
−1.33	$1''.6 < r < 3''.2$	Brandl et al. (1996)
−1.63	$3''.2 < r$	Brandl et al. (1996)
-1.17 ± 0.05	$4''.6 < r < 19''.2$	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)

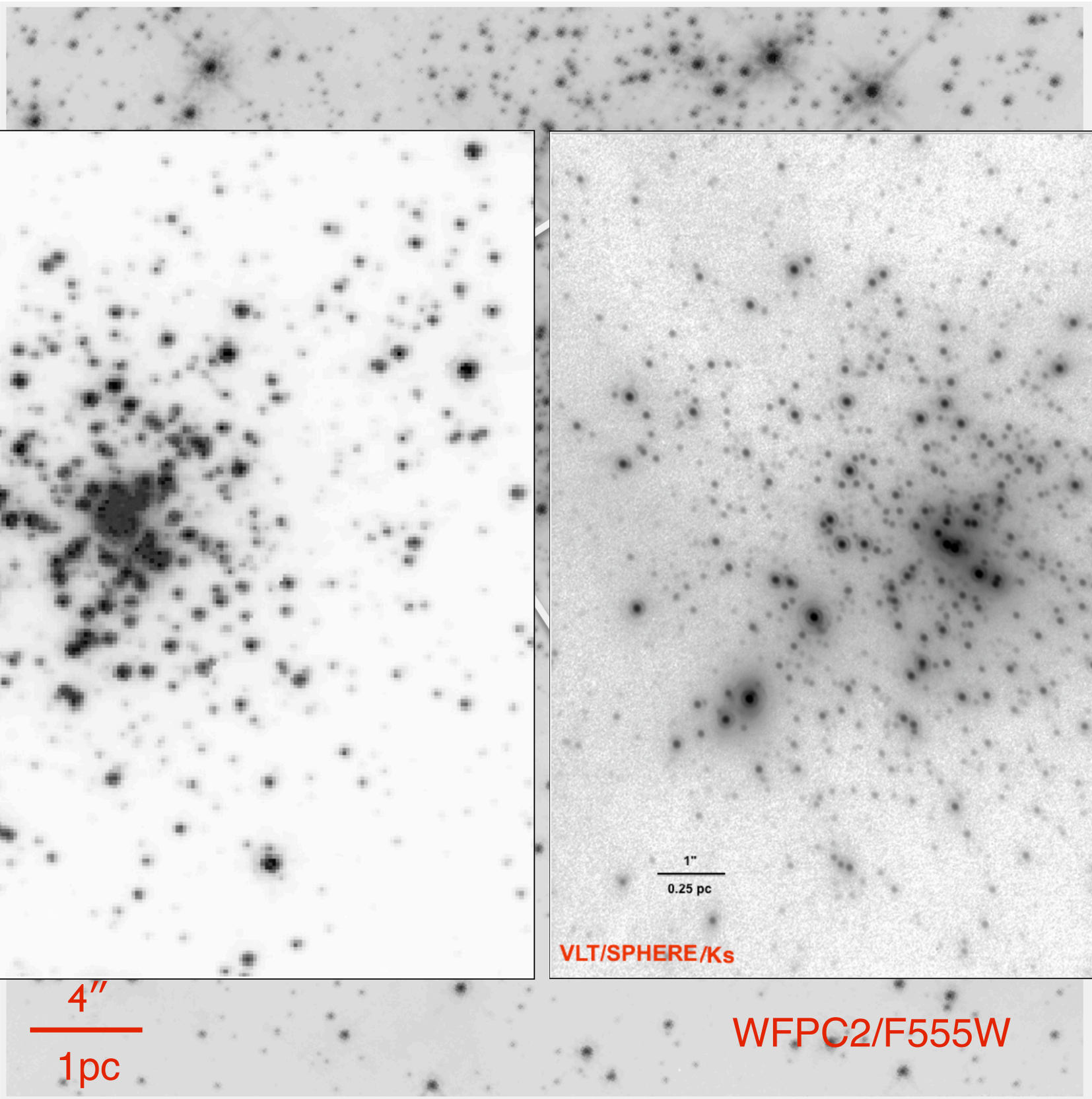
MF example: R136

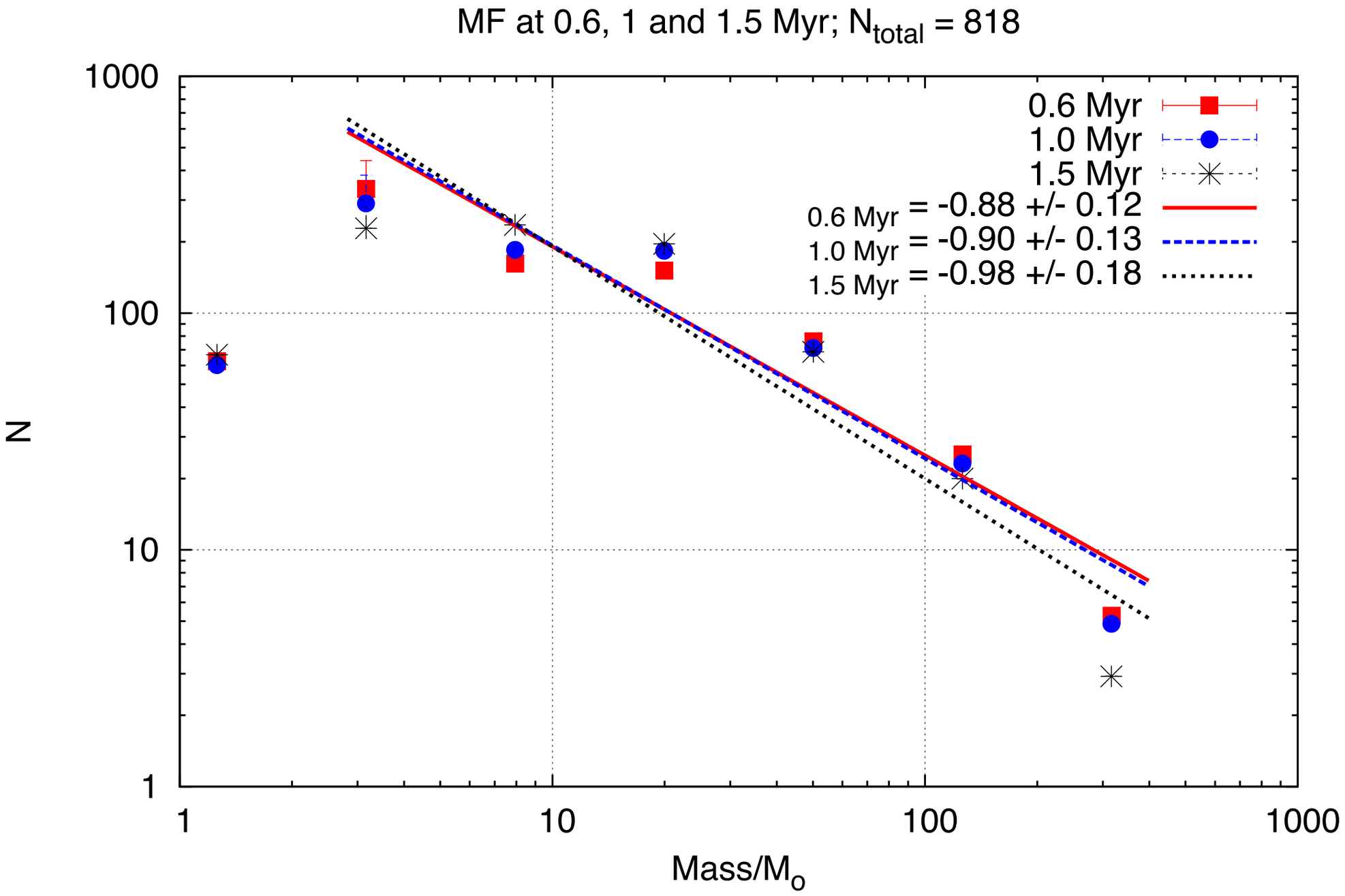


MF example: R136









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

MF is sensitive to the observations and models

How can we simulate observations?

Make Your Synthetic Observations

Inputs:

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

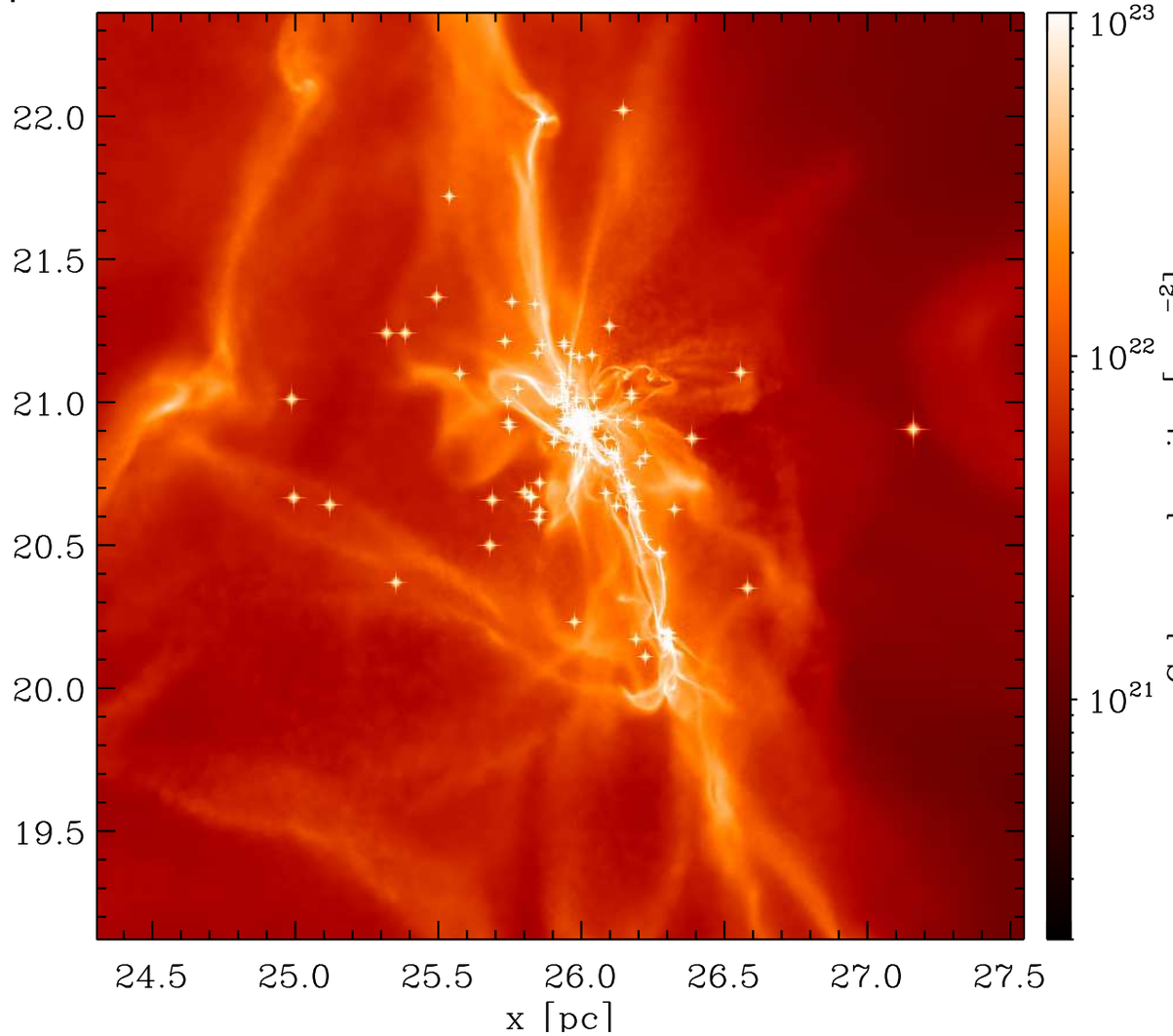
Observational Filter (from the list)
Imaging angular resolution AND Spectroscopic resolution

Distance of the centre of mass
FoV

R_v for extinction
Adaptive optics: seeing and SR

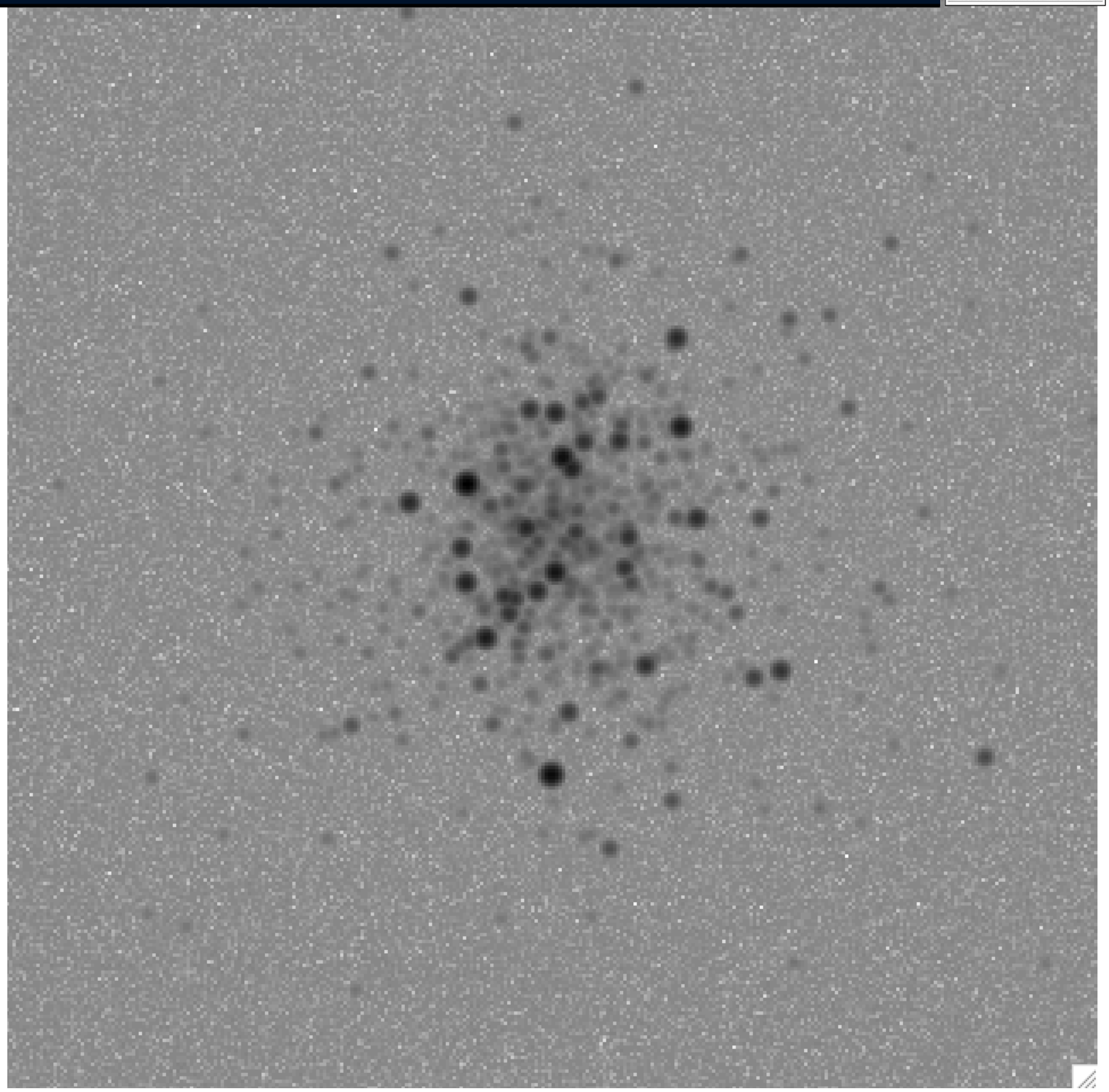
OB-treatment: TLUSTY model atmosphere

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



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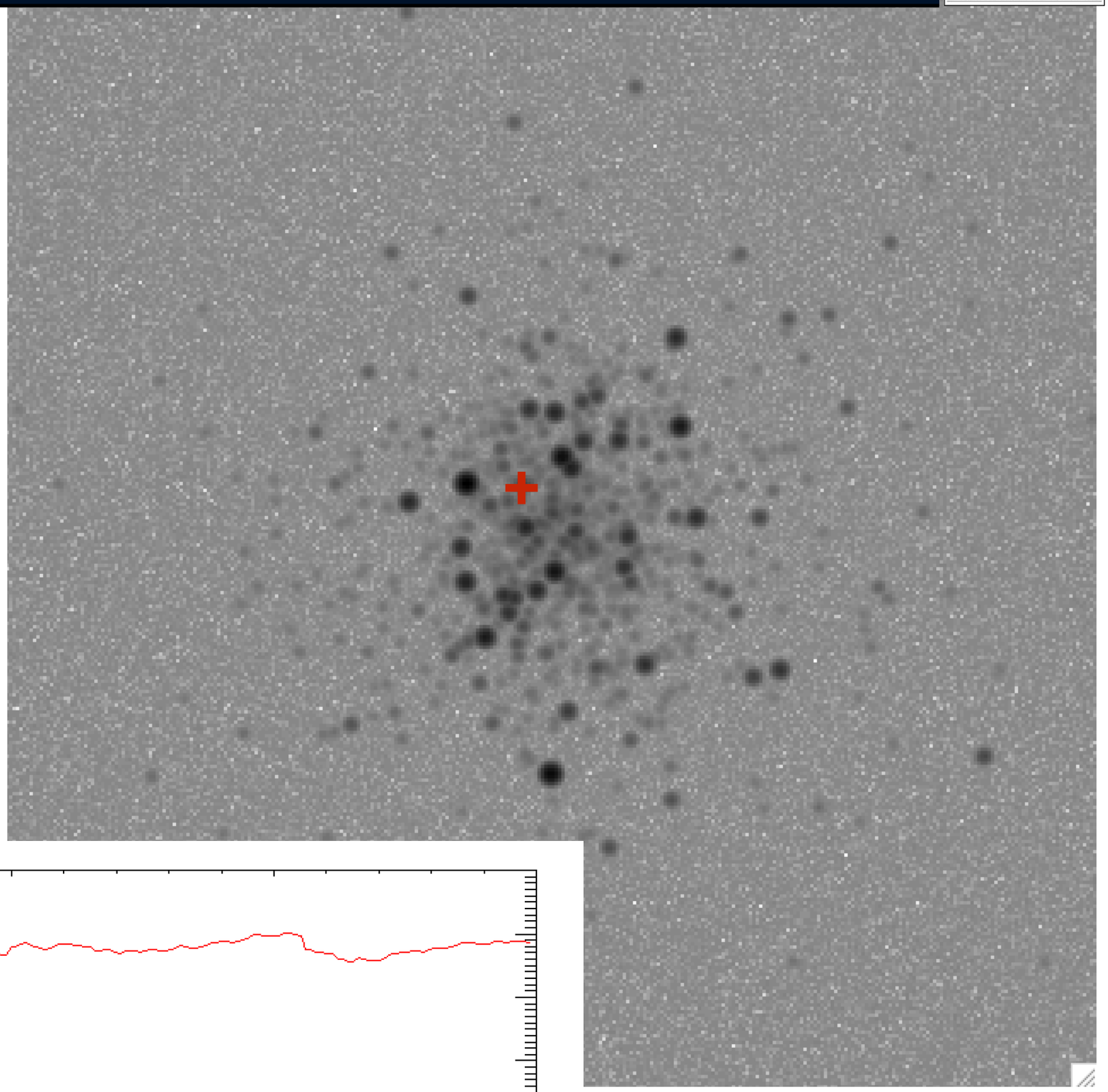
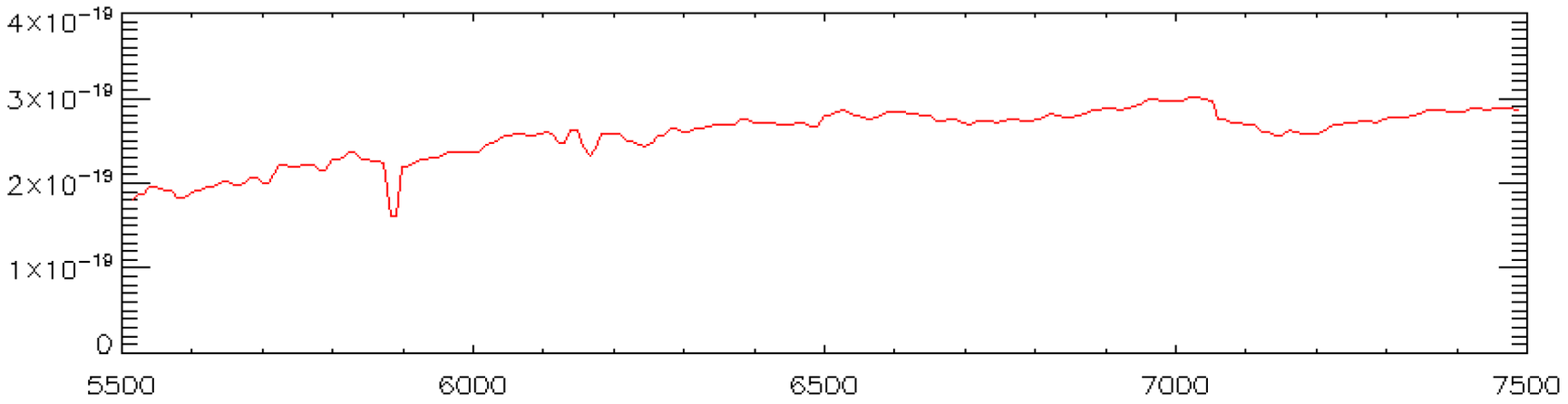
Gaia-G filter
R=700





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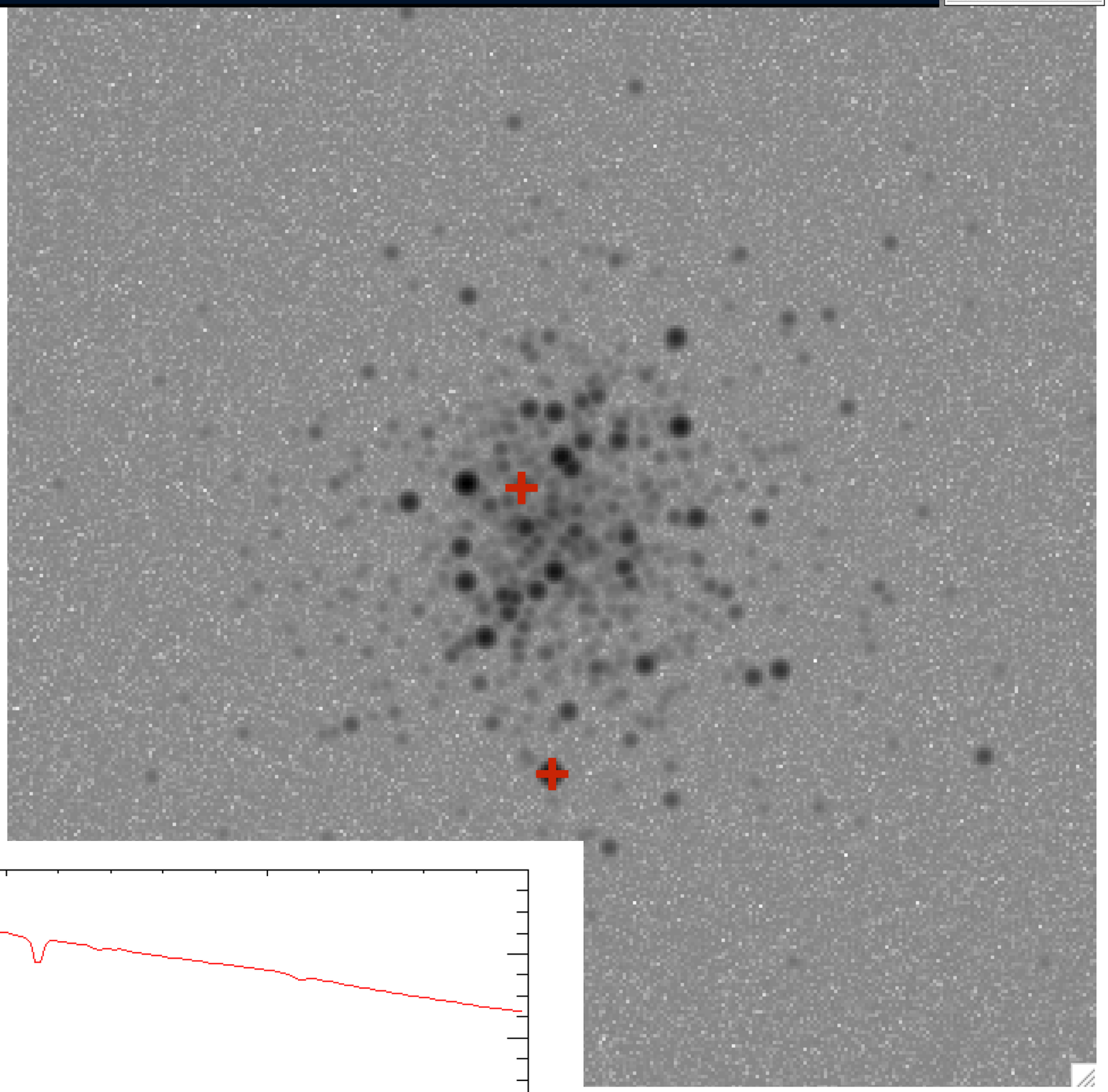
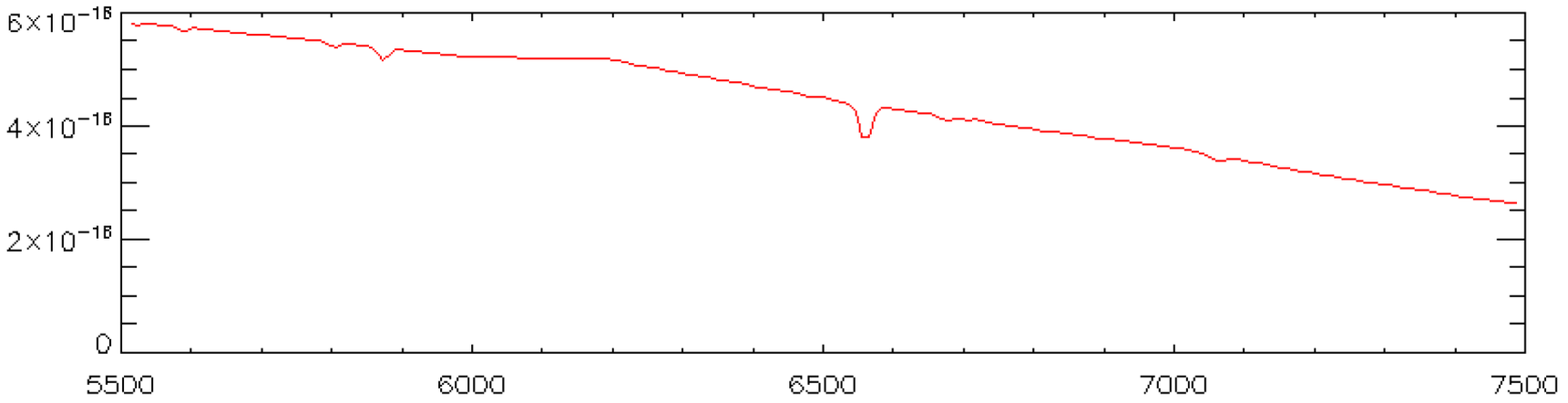
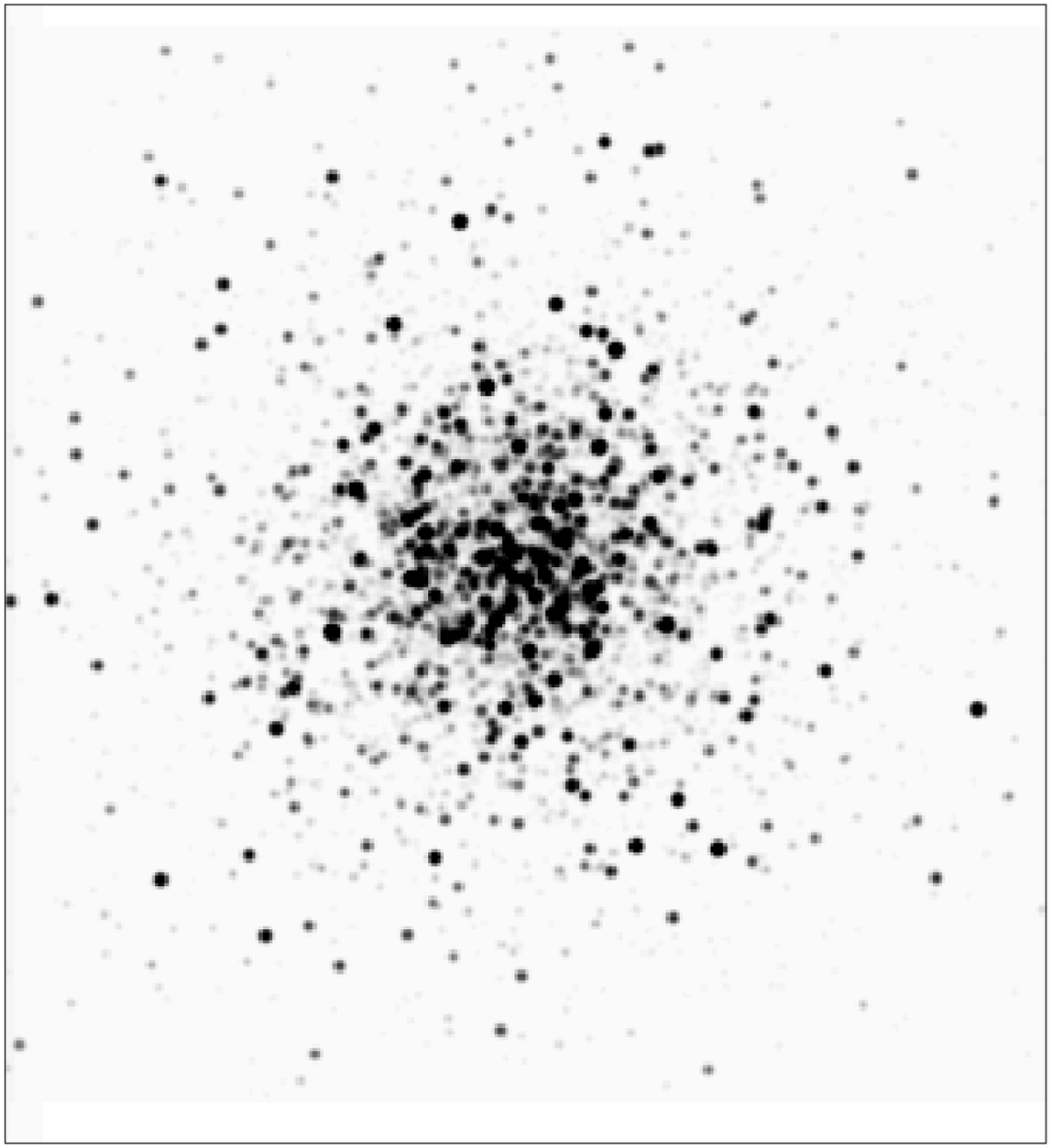
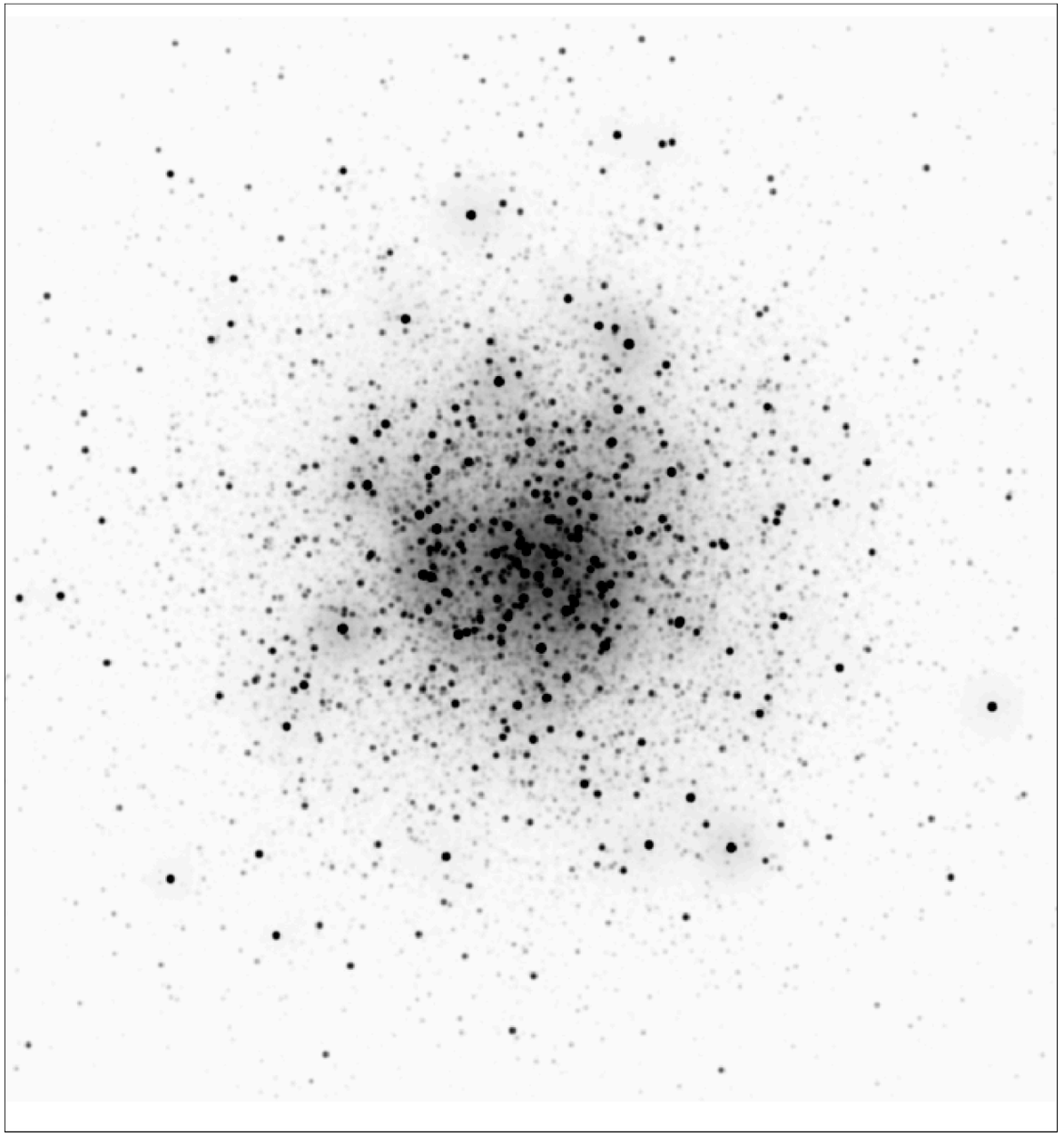




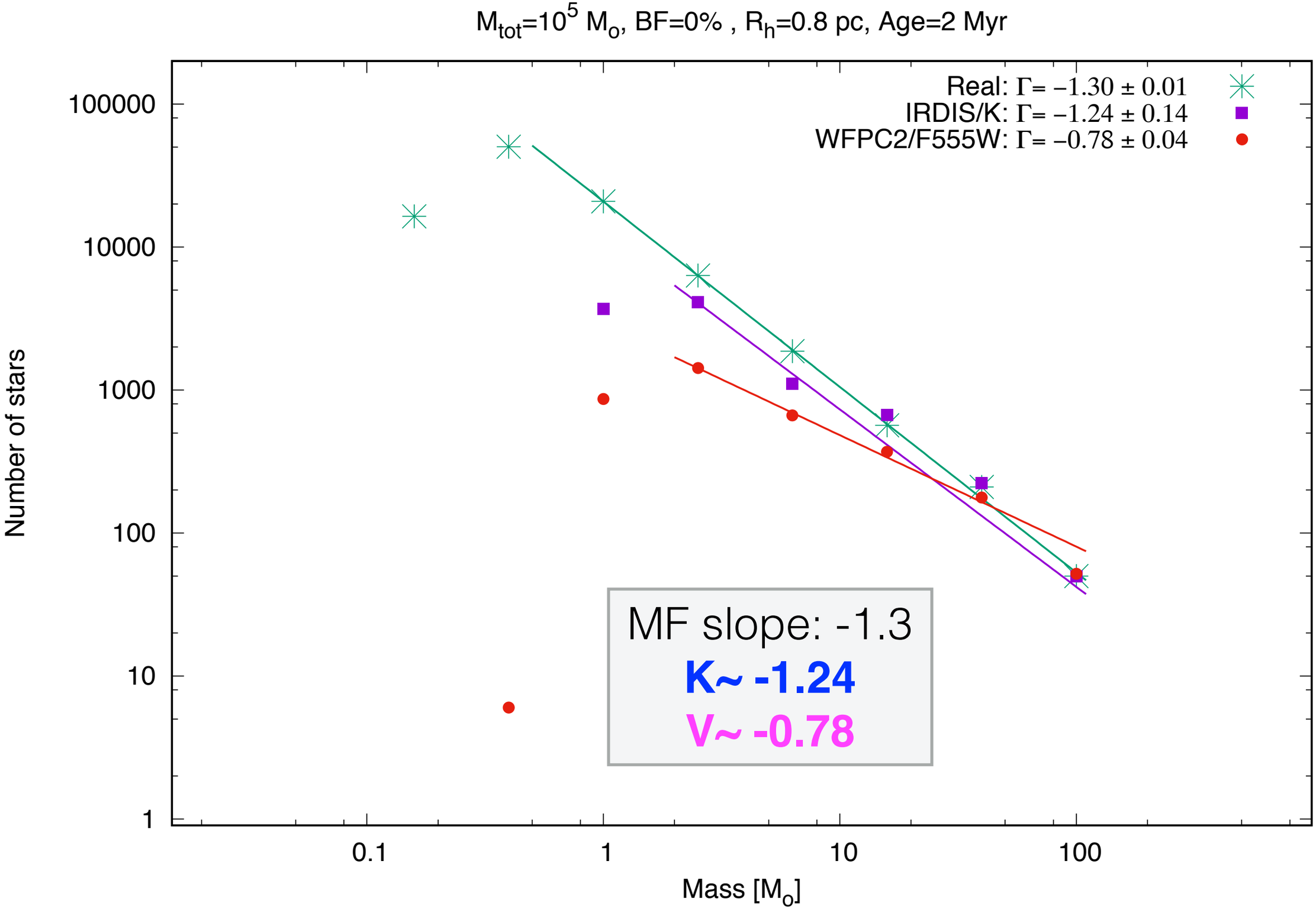
$M_{tot}=10^5\ M_o$, BF=0% , R_h=0.8 pc, Age=2 Myr



WFPC2/F555W

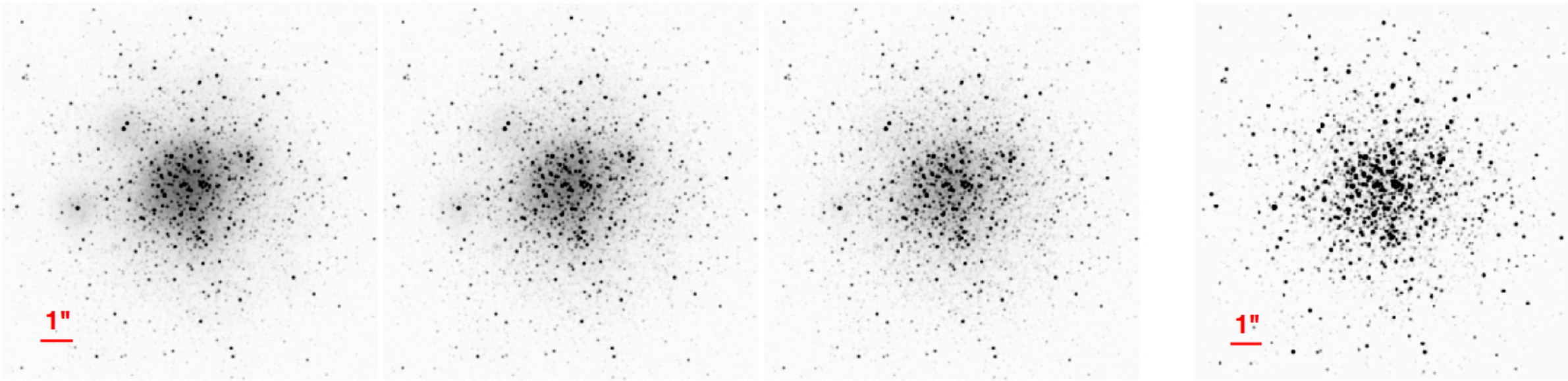


IRDIS/K
SR: 0.7

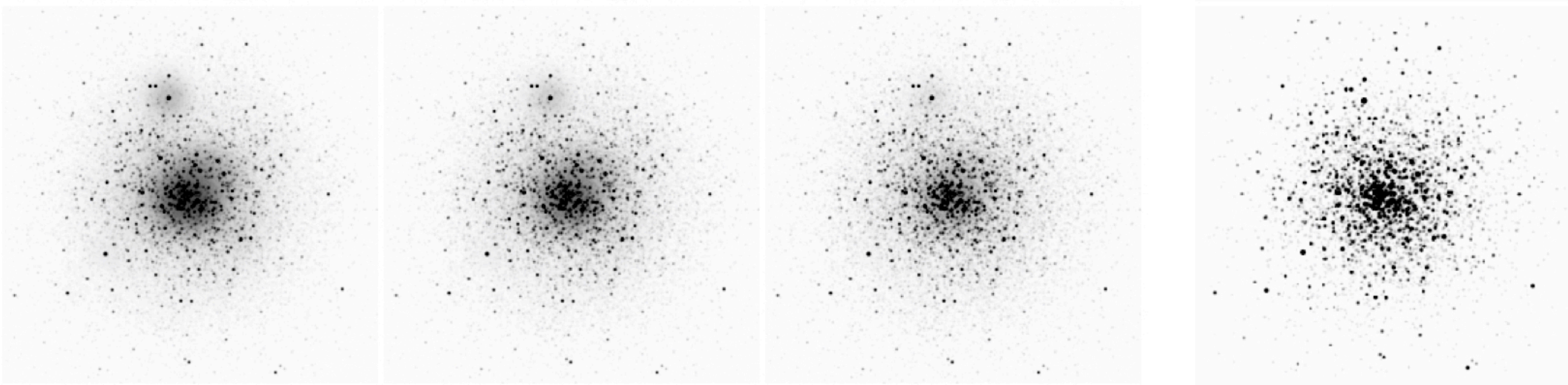

$M_{tot}=10^5$ M_o, BF=0% , R_h=0.8 pc, Age=2 Myr
Real: Γ= −1.30 ± 0.01
IRDIS/K: Γ= −1.24 ± 0.14
WFPC2/F555W: Γ= −0.78 ± 0.04
MF slope: -1.3
K~ -1.24
V~ -0.78
Number of stars
Mass [M_o]
100000
10000
1000
100
10
1
0.1
1
10
100

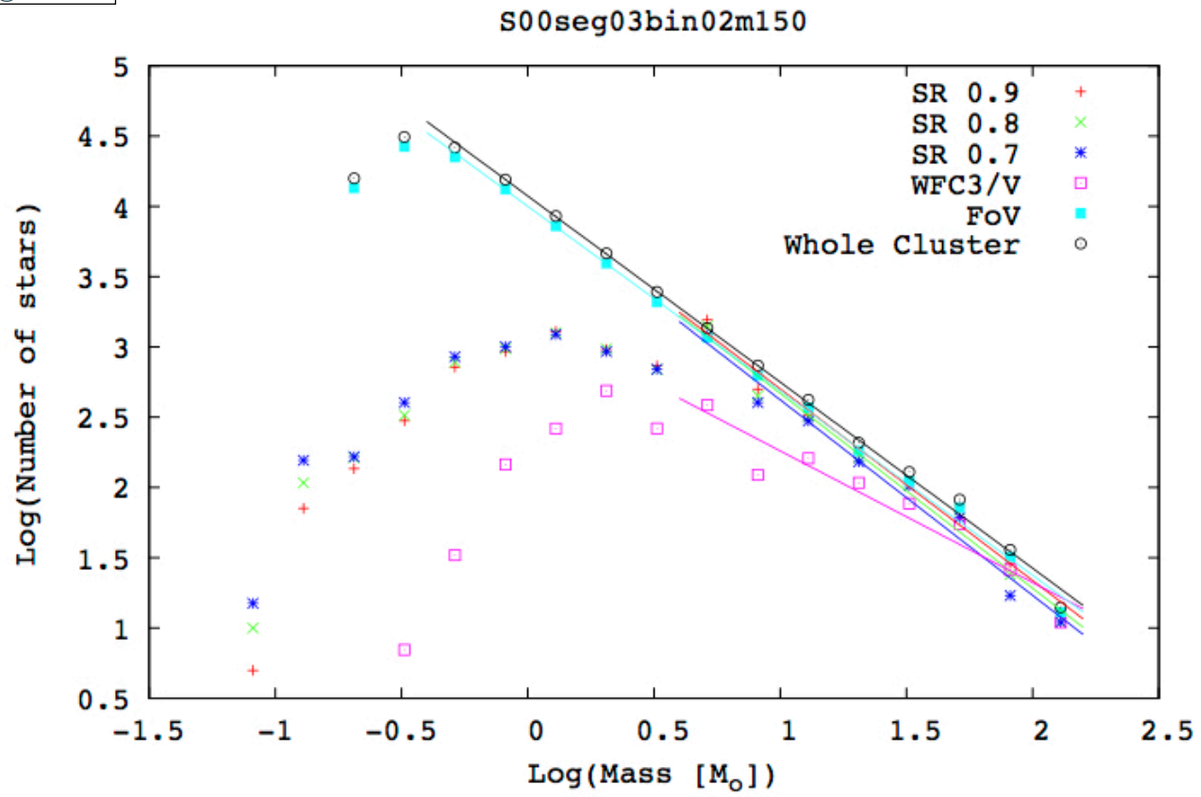
IRDIS/Ks: SR 0.7 | SR 0.8 | SR 0.9 | HST/WFC3/F555W

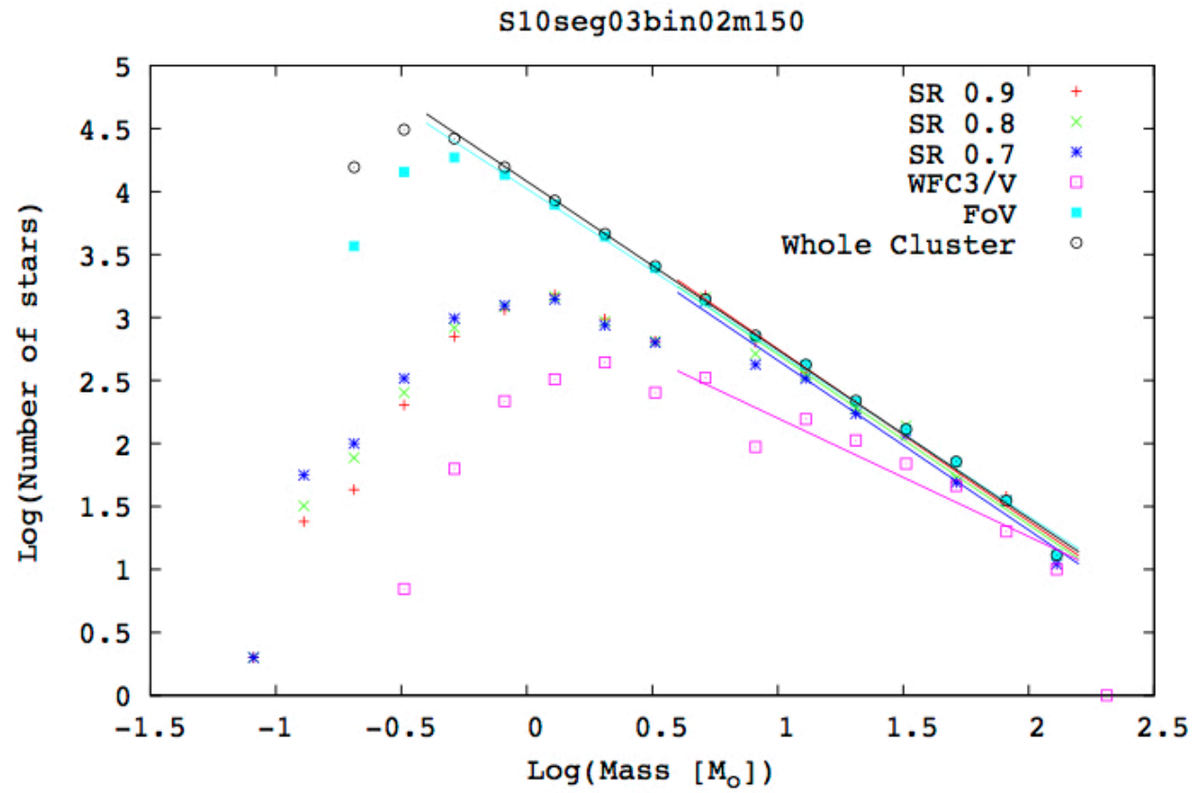
Non-segregated



Segregated

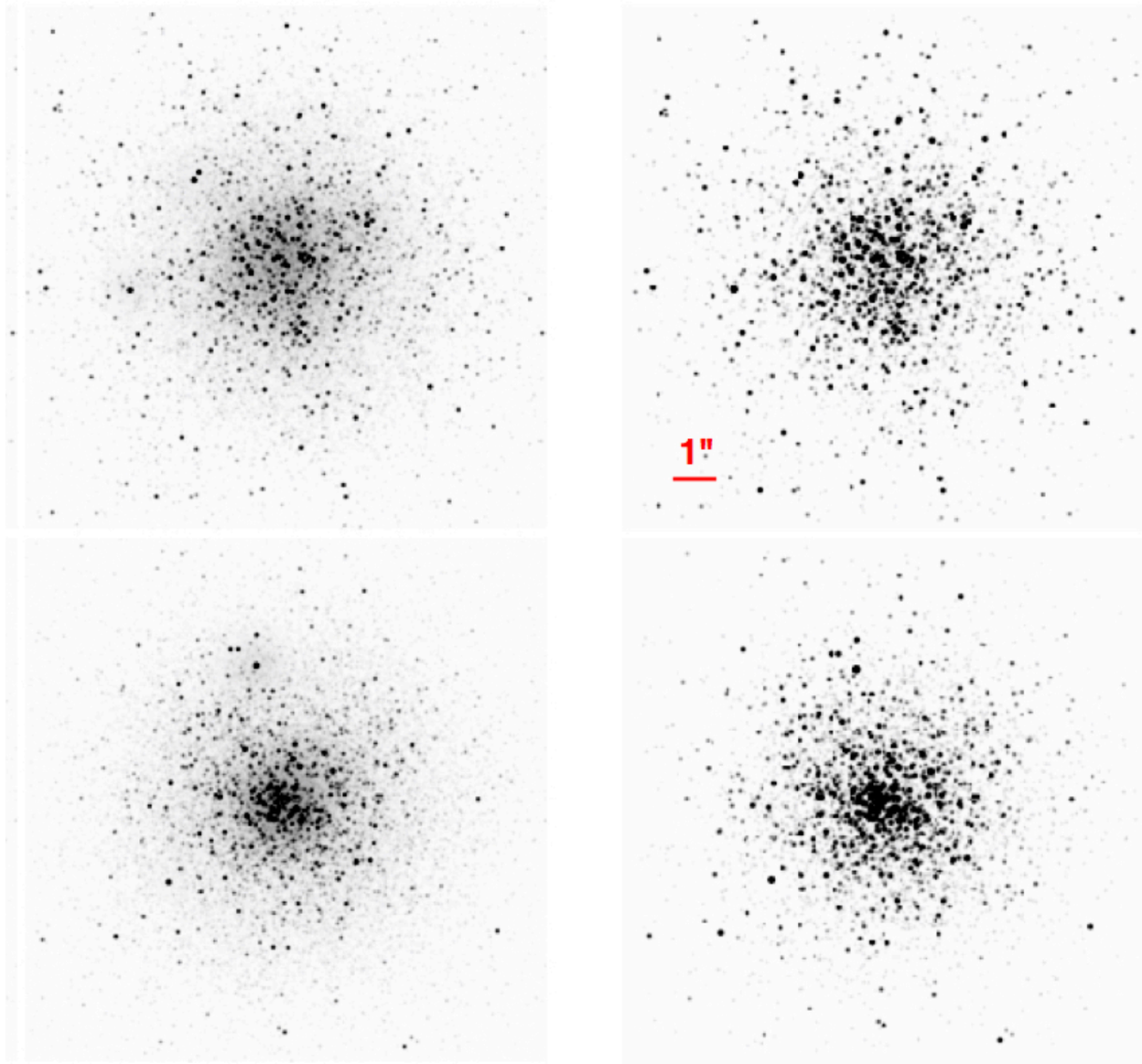






SR 0.9

HST/WFC3/F555W

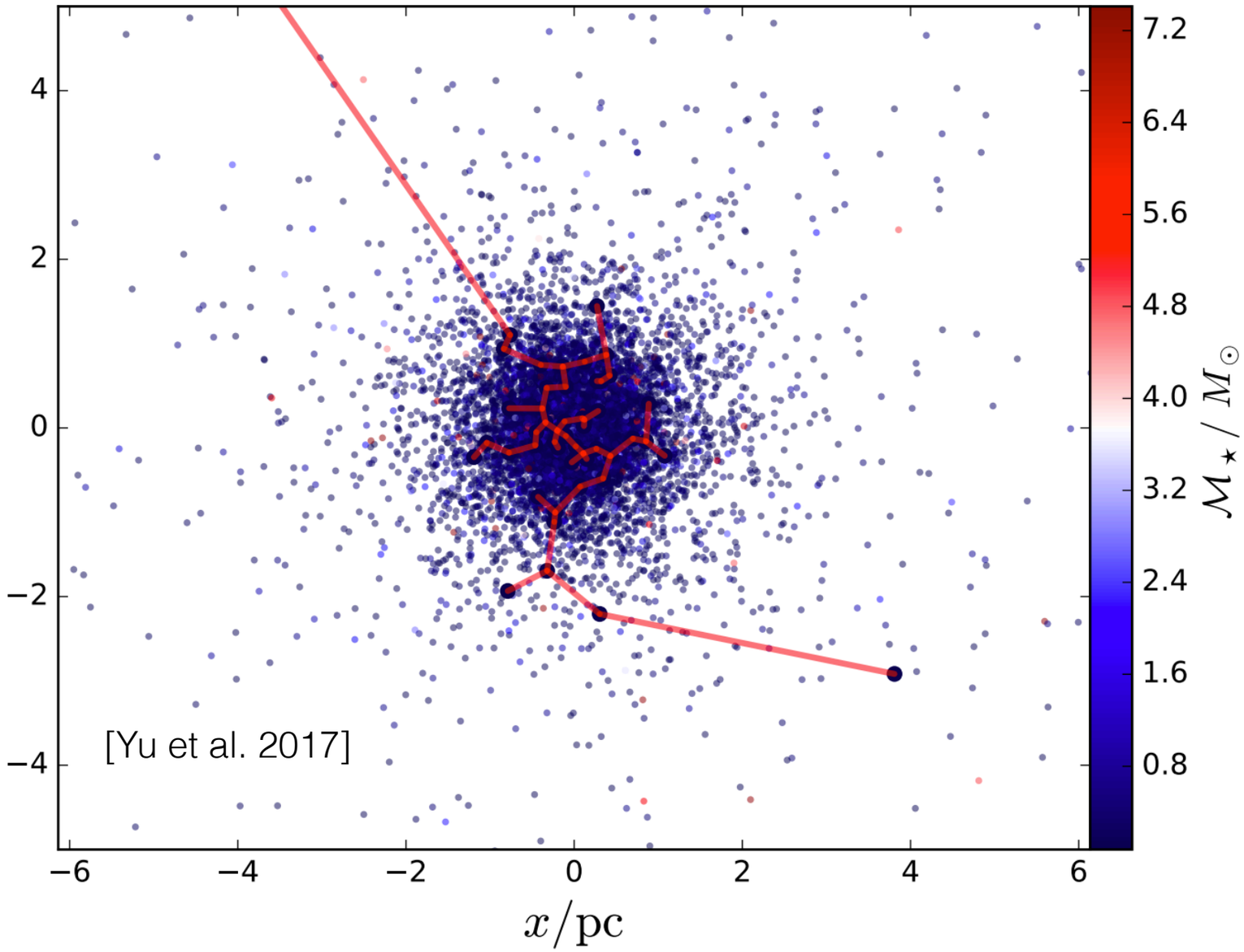


MF slope

K~ -1.38

V~ -0.93

Minimum Spanning Tree



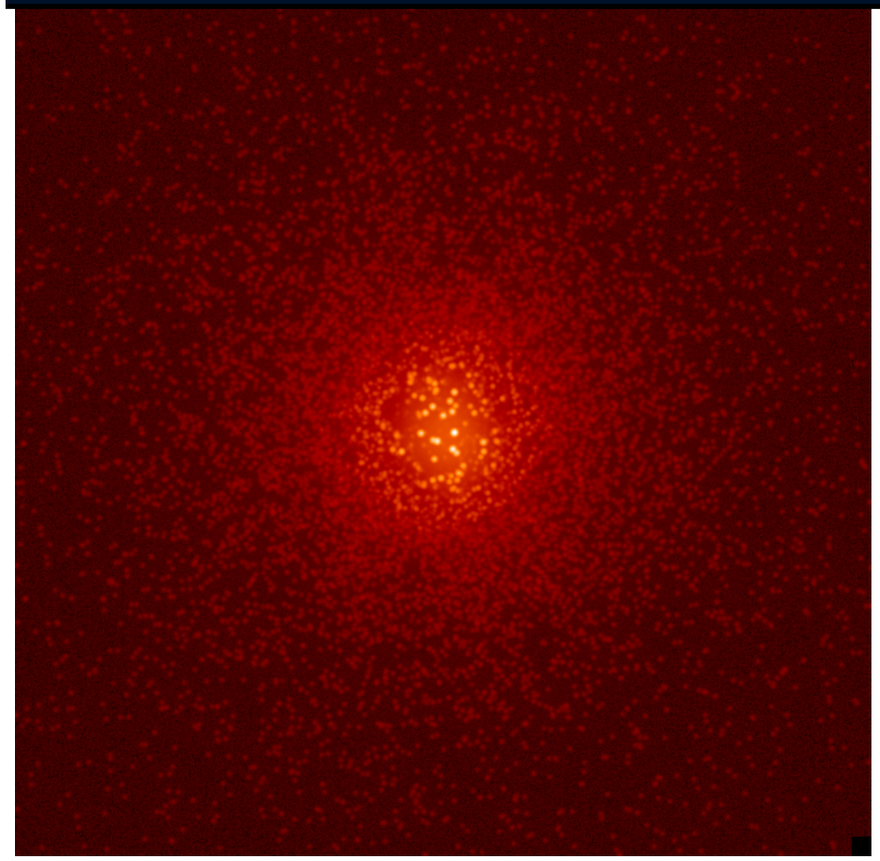
$$\Lambda_{\mathrm{MSR}} = \frac{\langle l_{\mathrm{norm}} \rangle}{l_{\mathrm{massive}}} \pm \frac{\sigma_{\mathrm{norm}}}{l_{\mathrm{massive}}}$$

Λ_{MSR} = 1.0: No-segregation

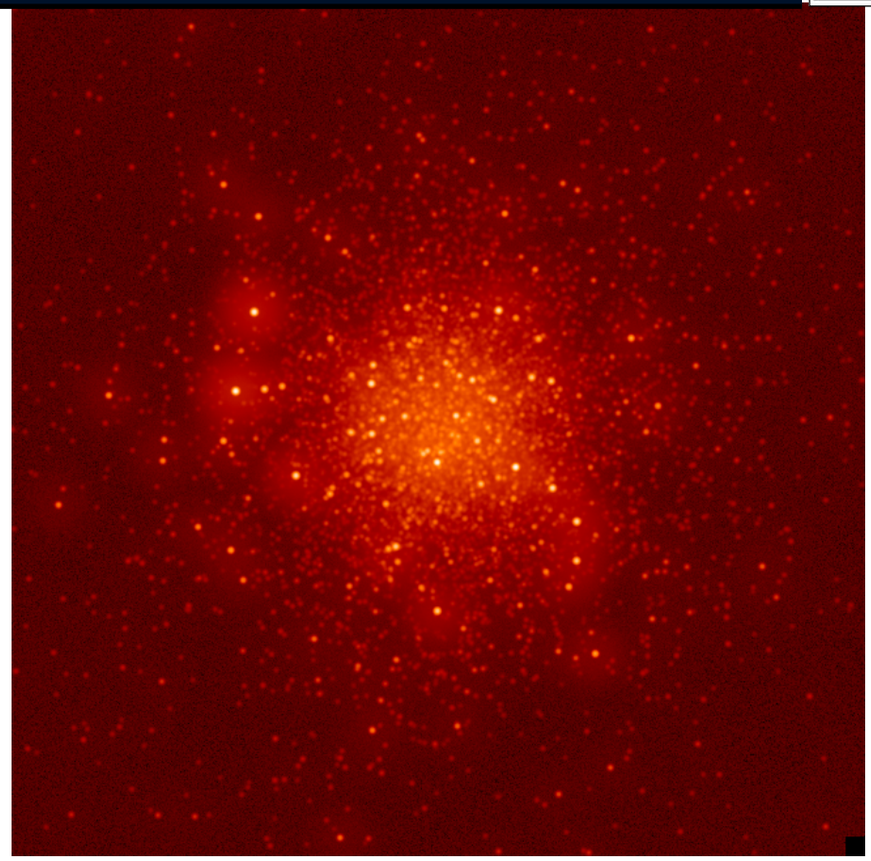
Λ_{MSR} > 1.0 : Segregated

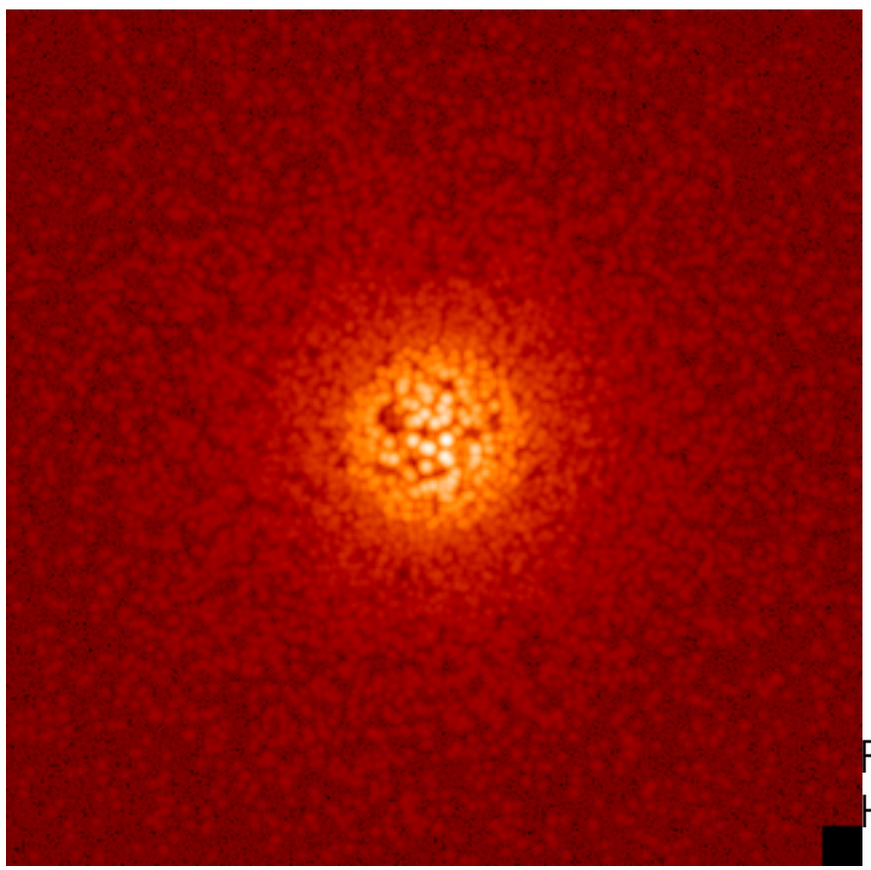
[Allison et al. 2009]

MST method for mass-segregation

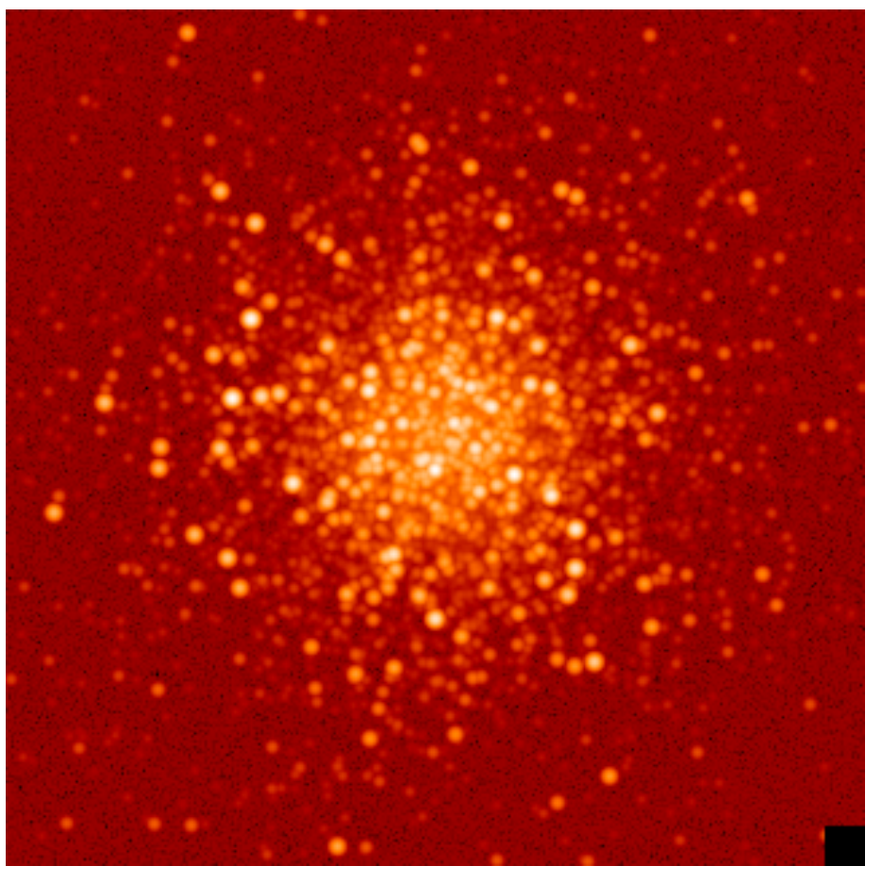


FoV: 16”x16”
VLT/SPHERE/K
SR=0.75
Seeing=0.8”

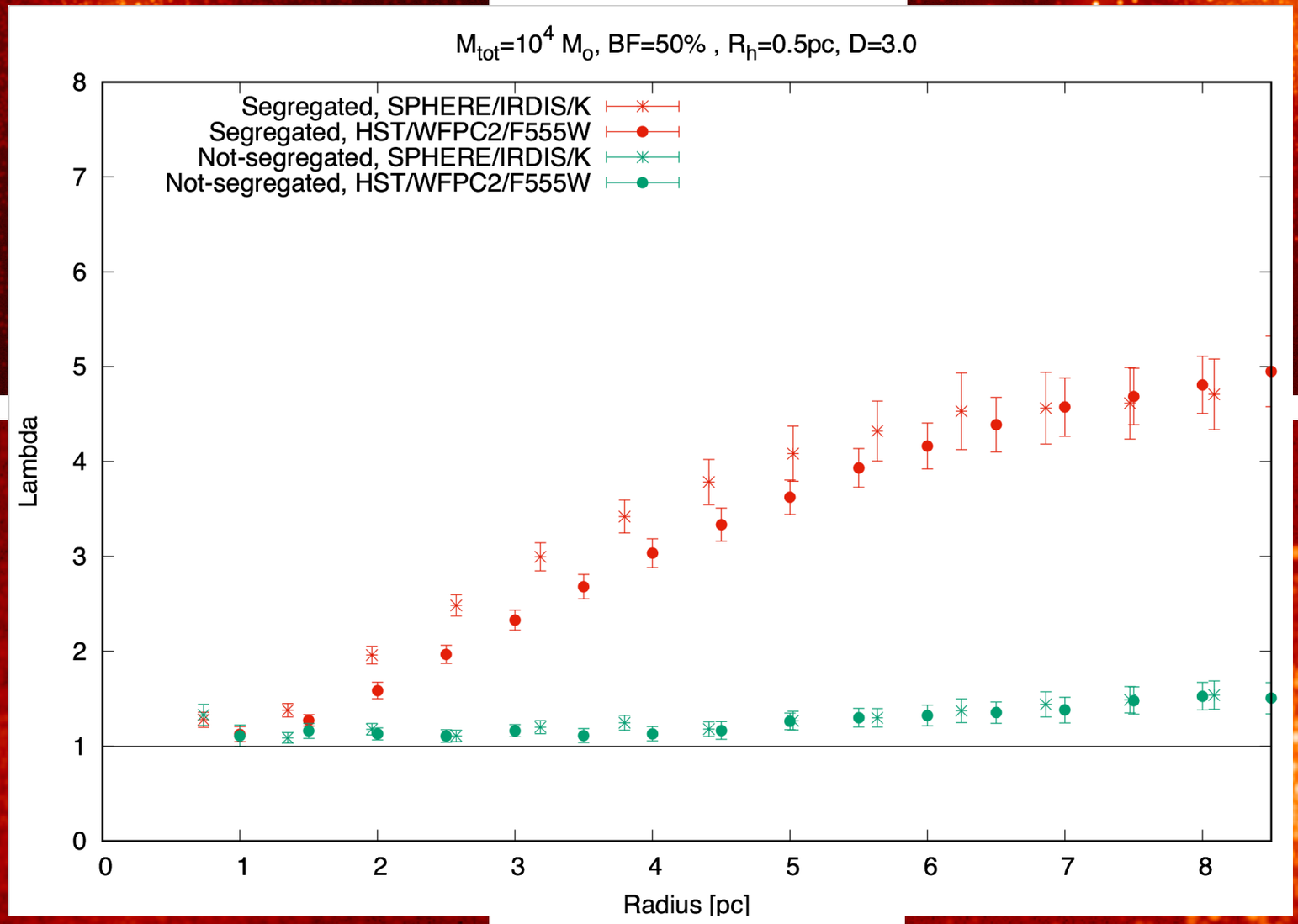




FoV: 16”x16”
HST/WFPC2/F555W

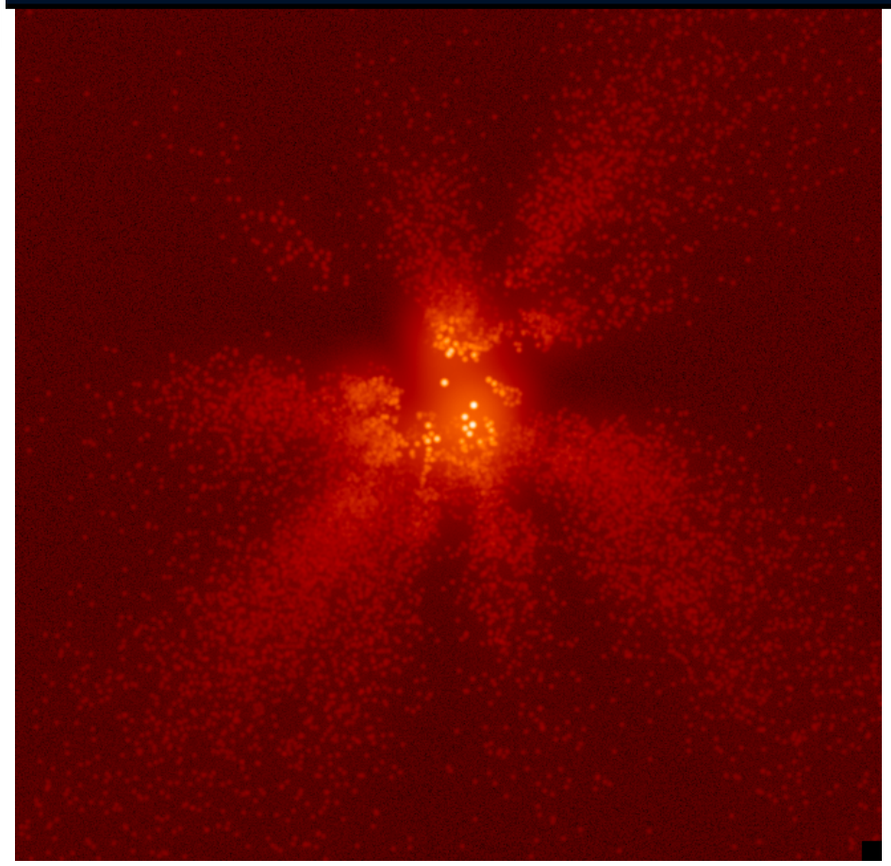


FoV: 16”x16”
VLT/SPHERE/K
SR=0.75
Seeing=0.8”

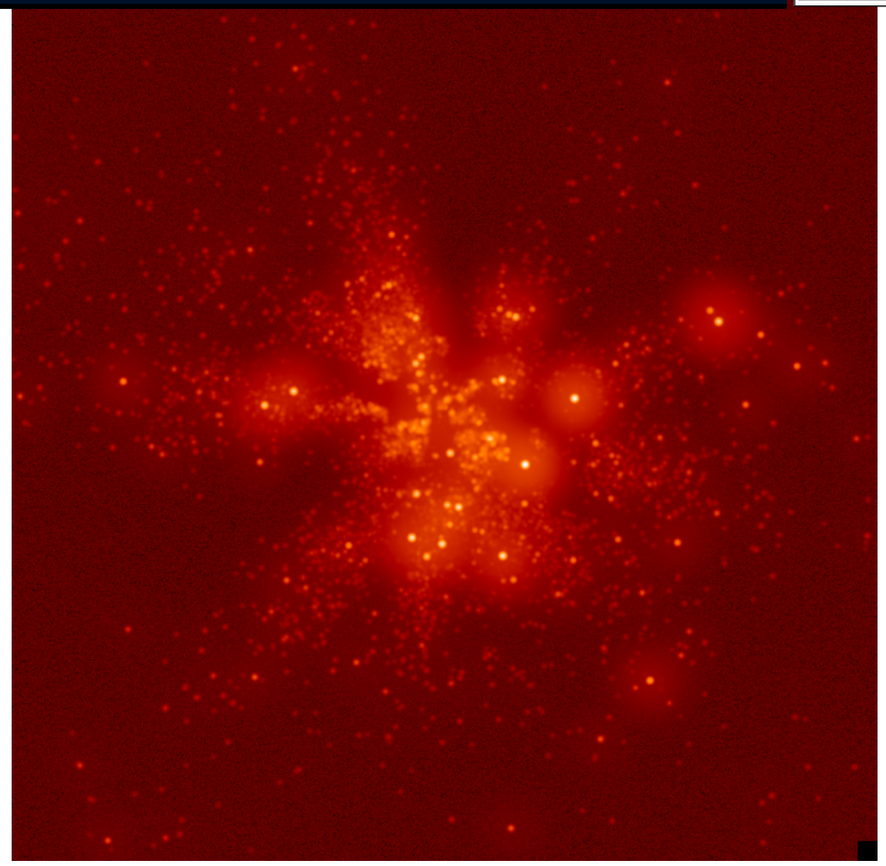


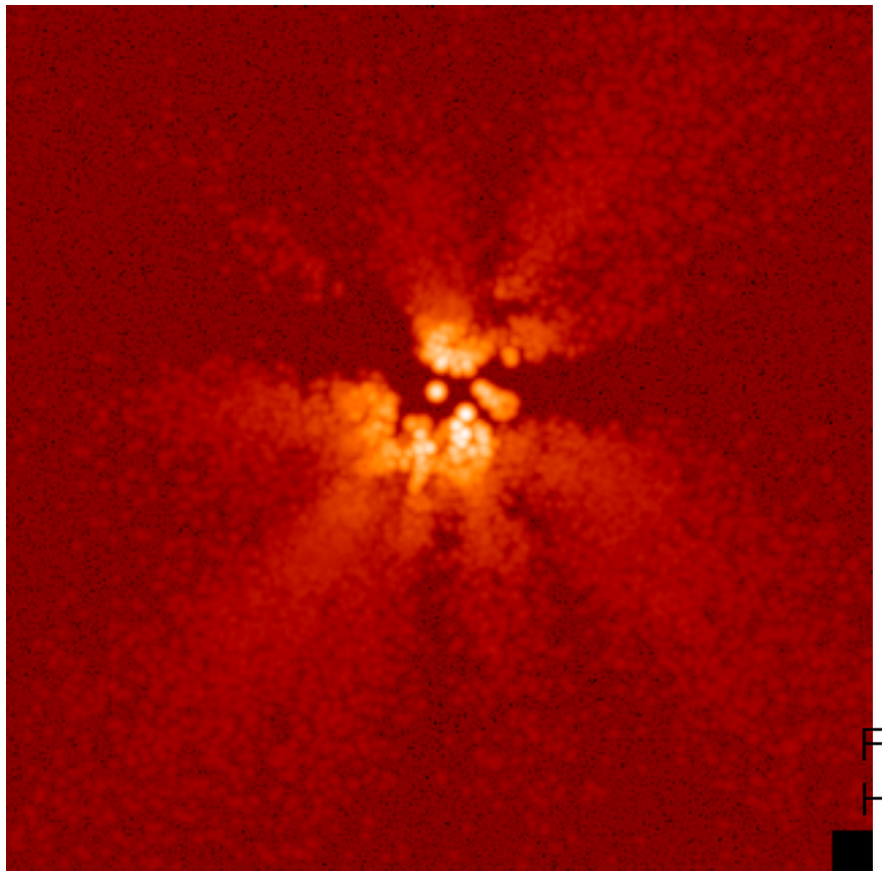
FoV: 16”x16”
HST/WFPC2/F555W

MST method for mass-segregation

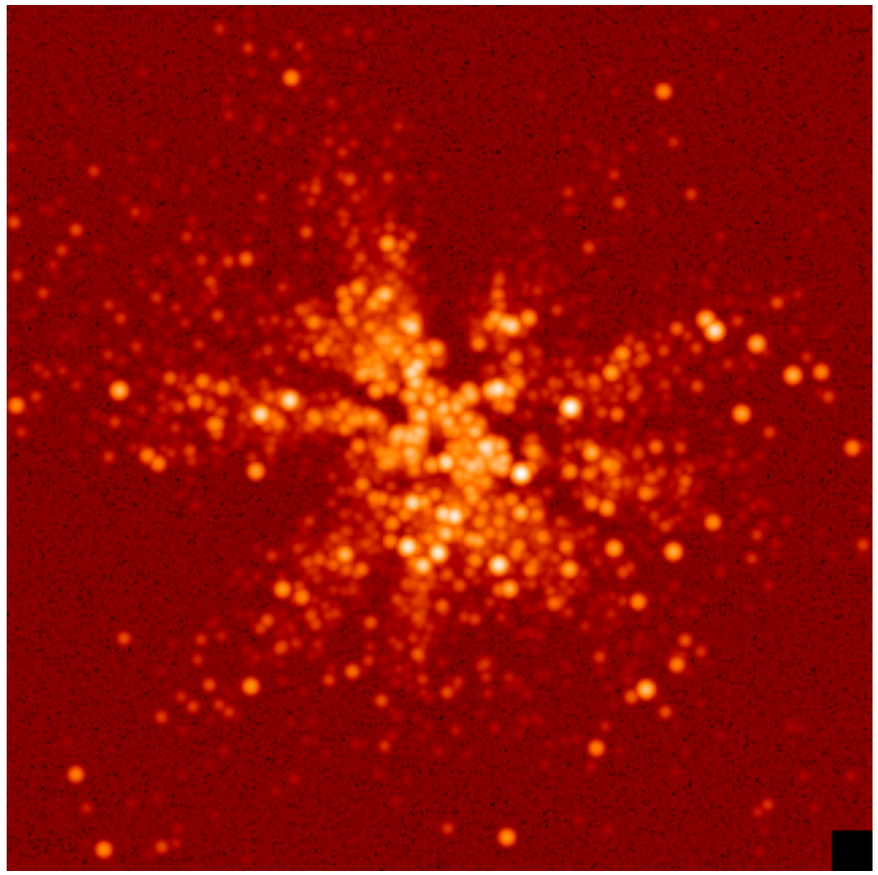


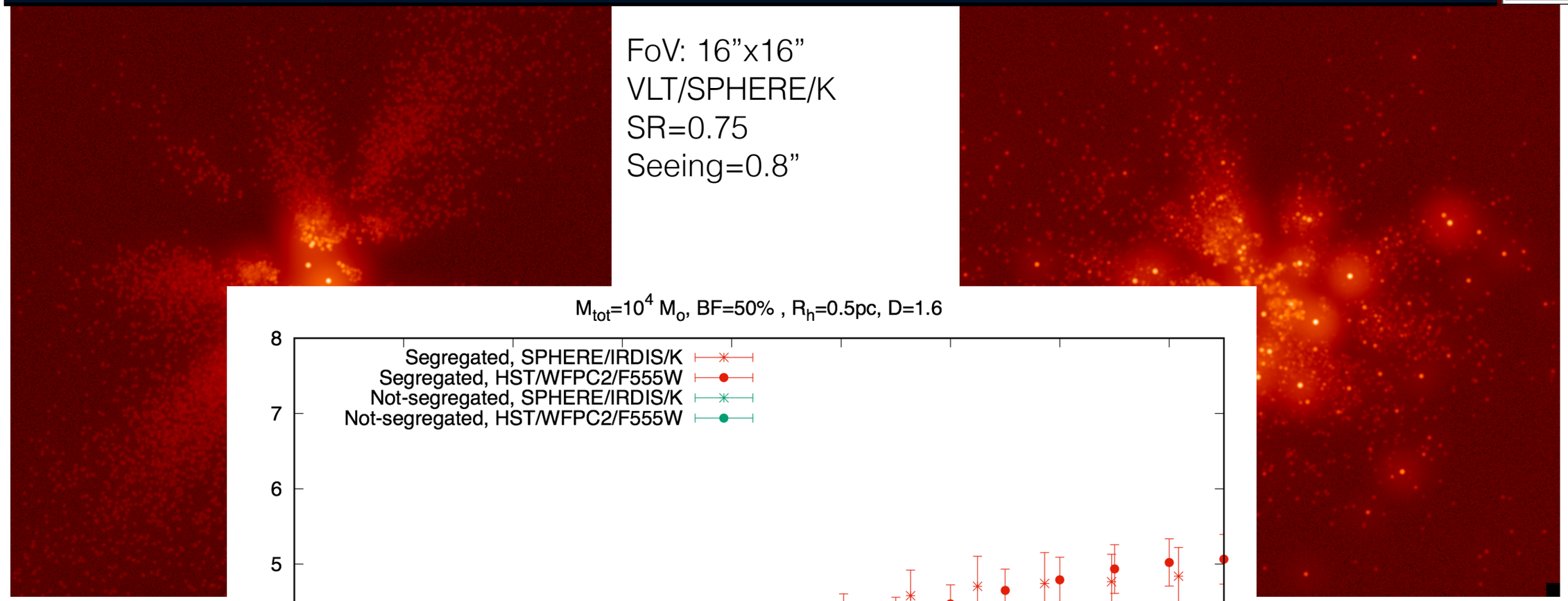
FoV: 16”x16”
VLT/SPHERE/K
SR=0.75
Seeing=0.8”





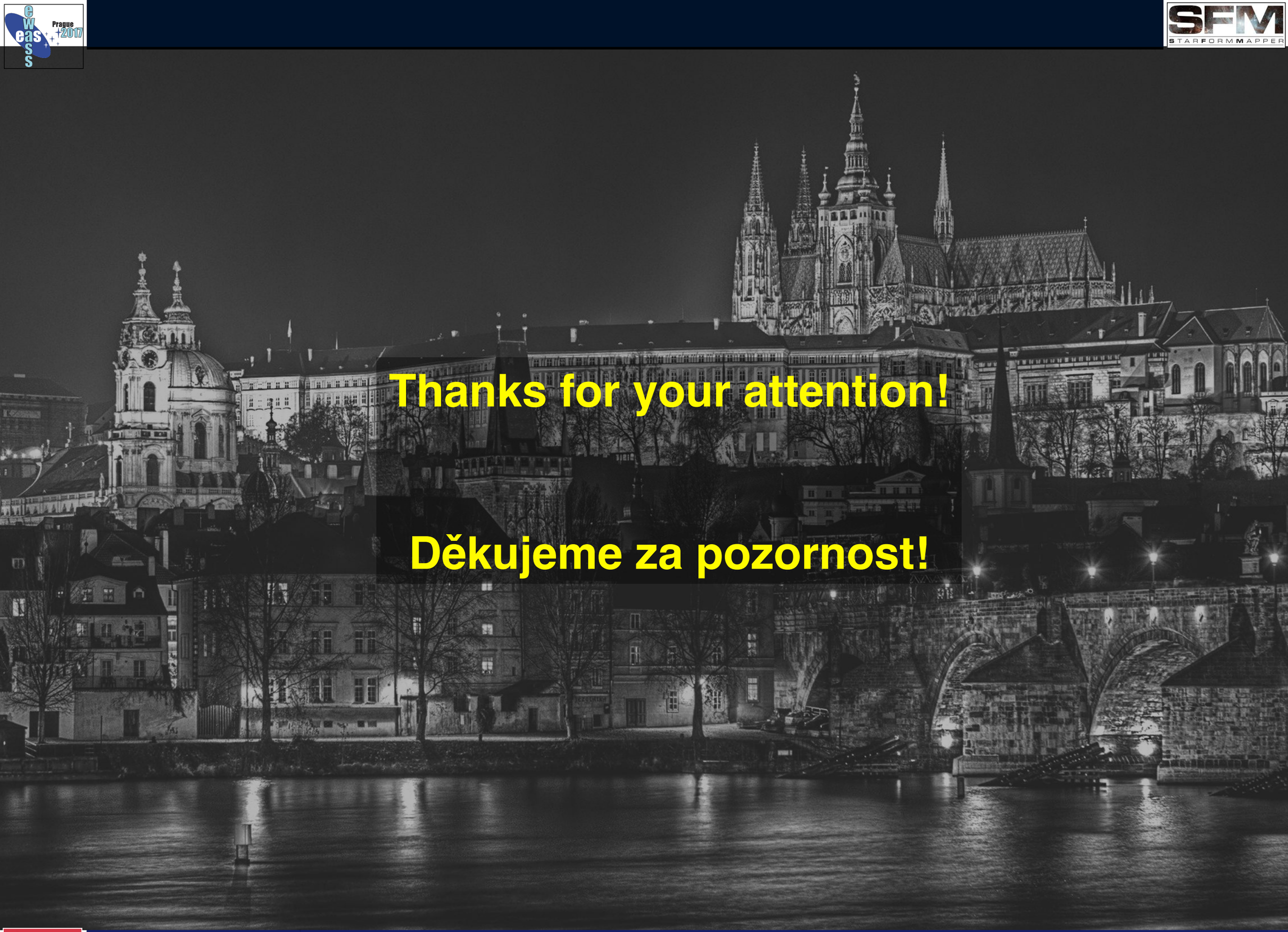
FoV: 16”x16”
HST/WFPC2/F555W




FoV: 16”x16”
VLT/SPHERE/K
SR=0.75
Seeing=0.8”
$M_{tot}=10^4$ M_o, BF=50% , R_h=0.5pc, D=1.6
Segregated, SPHERE/IRDIS/K
Segregated, HST/WFPC2/F555W
Not-segregated, SPHERE/IRDIS/K
Not-segregated, HST/WFPC2/F555W
Lambda
Radius [pc]
0
1
2
3
4
5
6
7
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
- Synthetic observations are needed to compare simulations with Observations
- MST method can detect mass-segregation in the simulated data


Thanks for your attention!
Děkujeme za pozornost!