The SUNBIRD survey: characterizing the super star cluster populations in LIRGs

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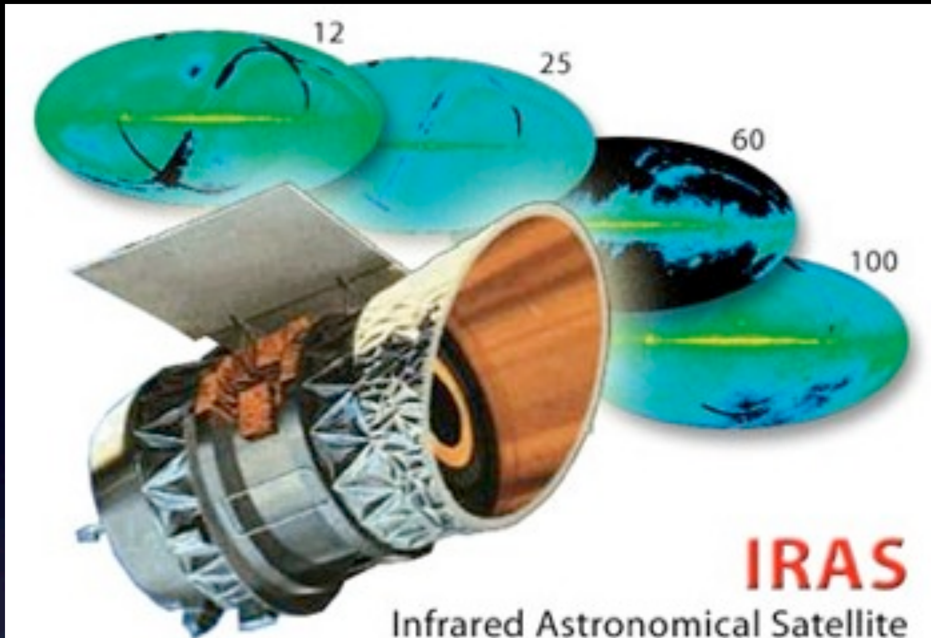
Outline

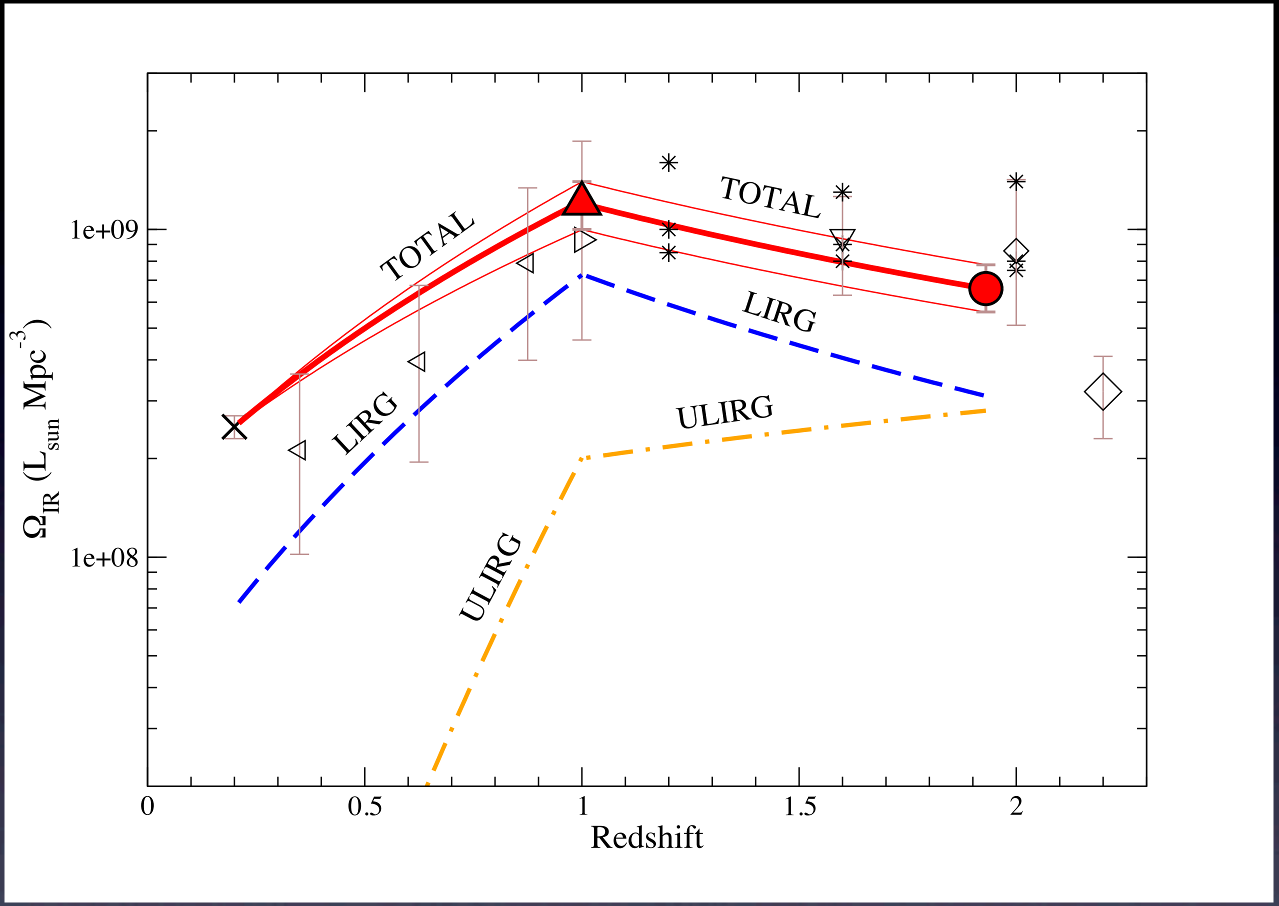
- Luminous infrared galaxies (LIRGs)
- The survey
- Super star clusters (motivation)
- Current results

Luminous infrared galaxies



- Total luminosities: 10 - 100 times the luminosity of the Milky Way
- ~90% of energy emitted at IR wavelengths
- Galaxy evolution is hidden behind dust!
- $10^{11} < L_{IR}(L_{\odot}) < 10^{12}$
- Almost all are interacting and/or merging systems
- SFR typically above $50 M_{\odot} \mathrm{yr}^{-1}$
- May also have AGN contribution (especially in the most luminous ones -- e.g. ULIRGs)
- A significant contribution toward the cosmic SFR

LIRGs and the co-moving IR energy density



Caputi+2007

Elbaz+2012
Le Floch+2005
Cowie+2004
Caputi+2007
Gruppioni+2013

(U)LIRGs are rare in the local Universe.

The major contributors of the CSFR from $z \sim 1$ and further beyond.

The SUNBIRD survey

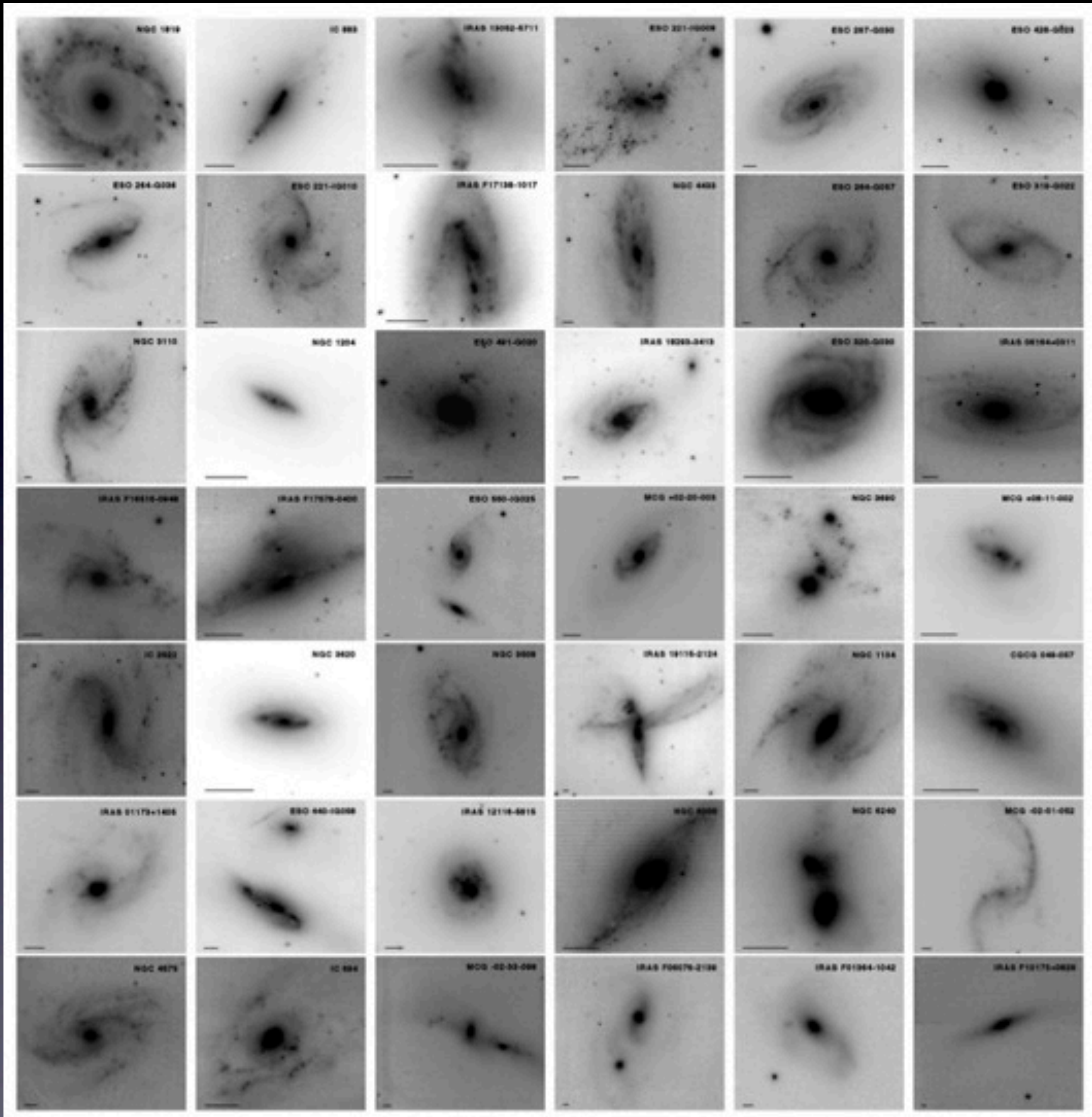
(SUperNovae and starBursts in the InfraReD)

To understand the star-formation histories of intensely star-forming galaxies

Science goals: star formation mechanisms, metallicities & kinematics, gas inflows/outflows, search for core-collapse SNe, study super star clusters (SSCs)

Sample: 42 galaxies including local starbursts and interacting LIRGs imaged with *K*-band NIR adaptive optics. Ancillary data from HST and VLA observations (+40 more, ongoing).

See Ryder et al (2014, arXiv: 1408.0598)



Randriamanakoto et al. 2013 a,b

The sample

- Gemini-N, ALTAIR/NIRI
- VLT/NACO S27/S54

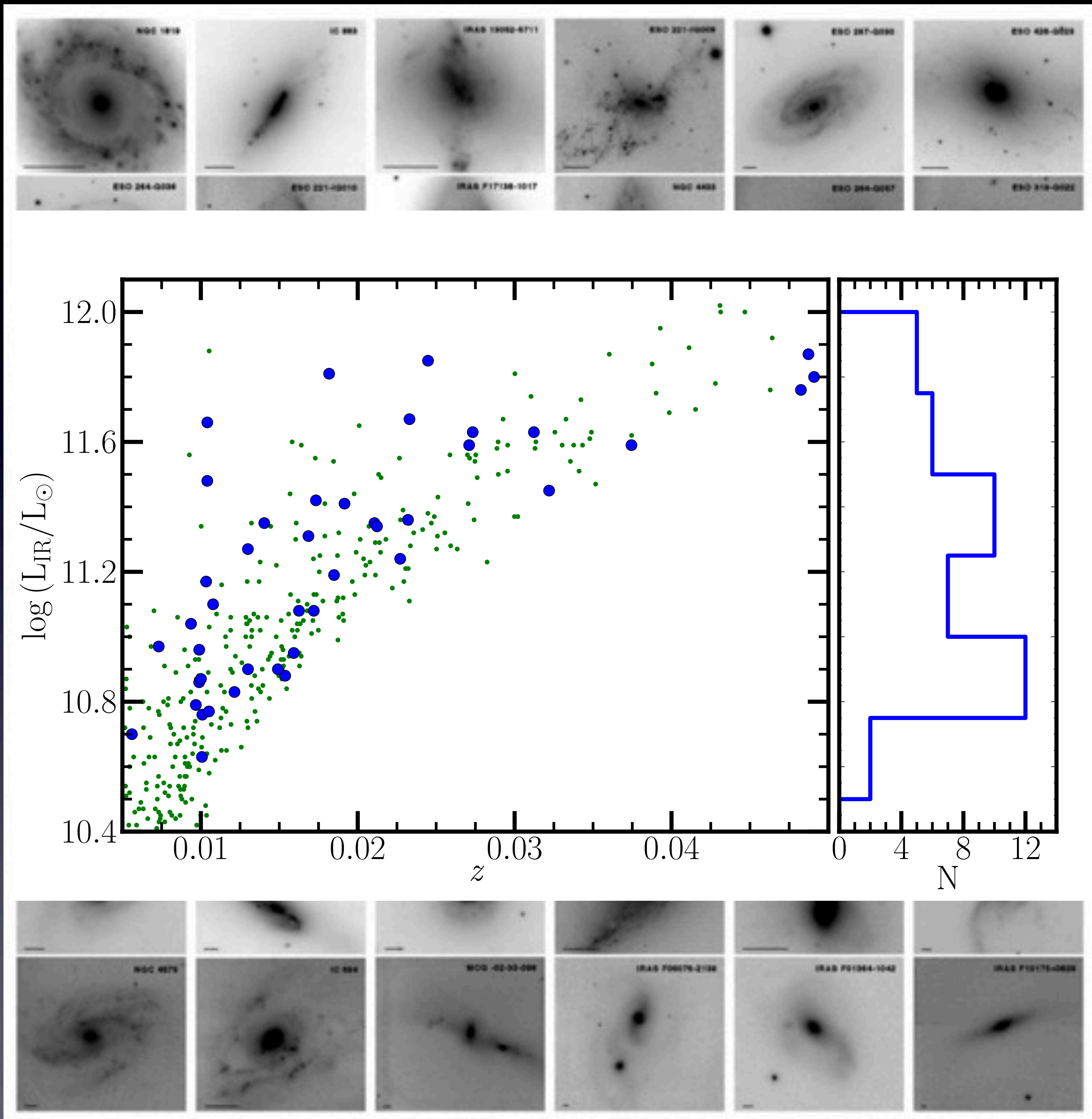
$30 \lesssim D_L\,(Mpc) \lesssim 200$

$10.6 \lesssim \log\,(L_{IR}/L_{\odot}) \lesssim 11.9$

$7 < \mathrm{SFR}\,(M_{\odot}yr^{-1}) < 120$

PSF resolution ~ 0.1”

The sample



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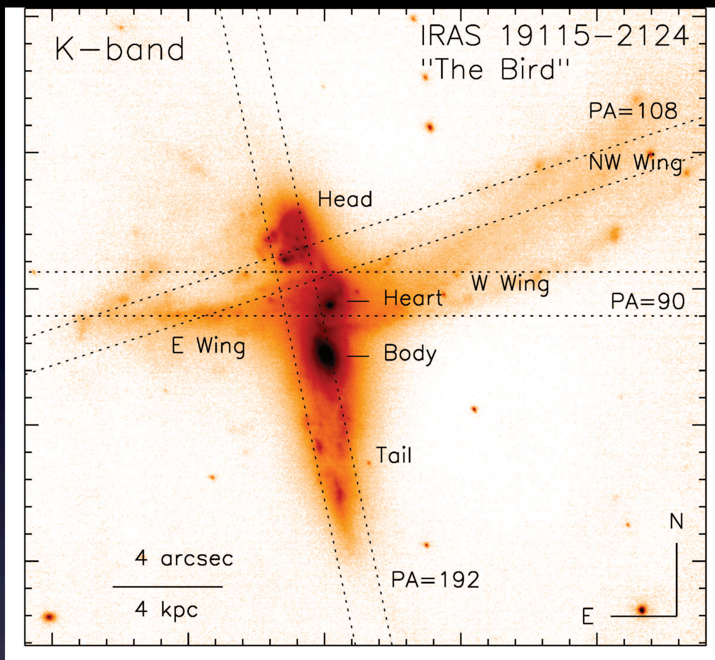
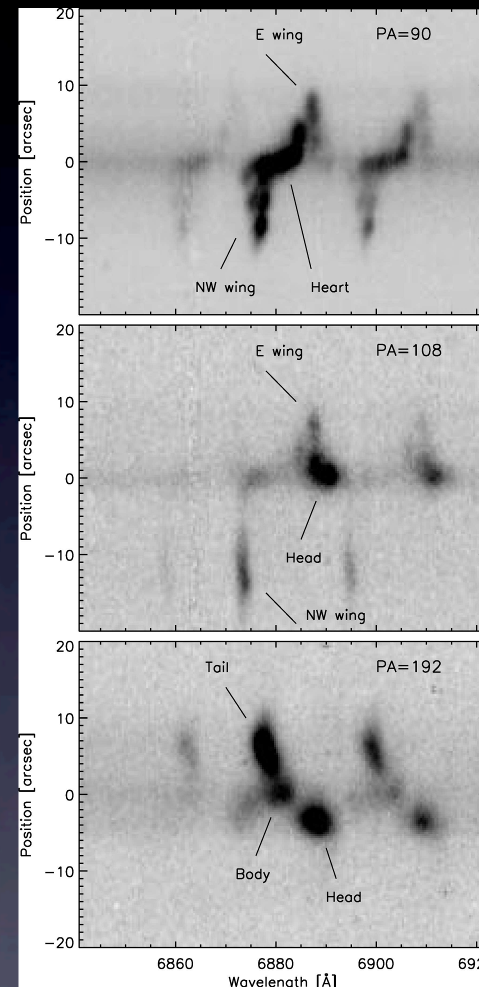
The SUNBIRD/SALT survey
(SUperNovae and starBursts in the InfraReD)

Southern African Large Telescope
in Sutherland South Africa
(www.salt.ac.za)





Vaisanen+2007

Spectroscopic observations using the long-slit RSS for spatially-resolved spectra of 30+ LIRGs (PhD thesis, Rajin Ramphul):

- stellar populations and SFHs from continuum
- metallicities from both continuum and emission lines
- H-alpha and NaD lines probing warm and cool ISM flows, mass loading, kinematics

ALL as a function of the LIRG environment and interaction stage

The SUNBIRD/SALT survey
(SUperNovae and starBursts in the InfraReD)

Legacy from the CCSNe datasets

Super star cluster (SSC) studies using NIR AO imaging

The capabilities of NIR AO systems

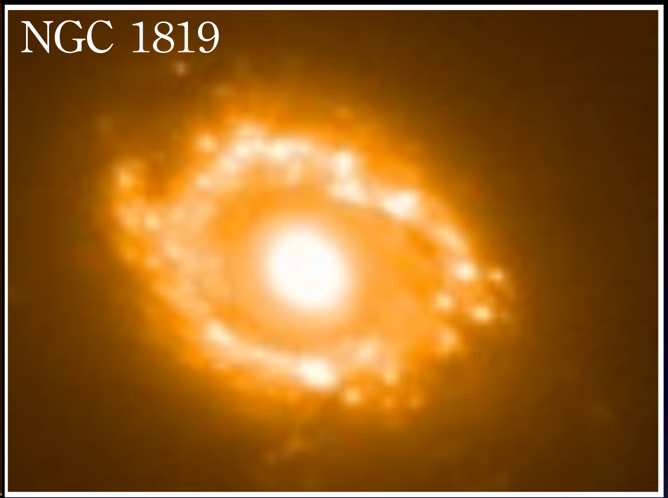
Optical - HST/ACS

NIR-VLT/NACO

High angular resolution

PSF ~ 0.1 arcsec

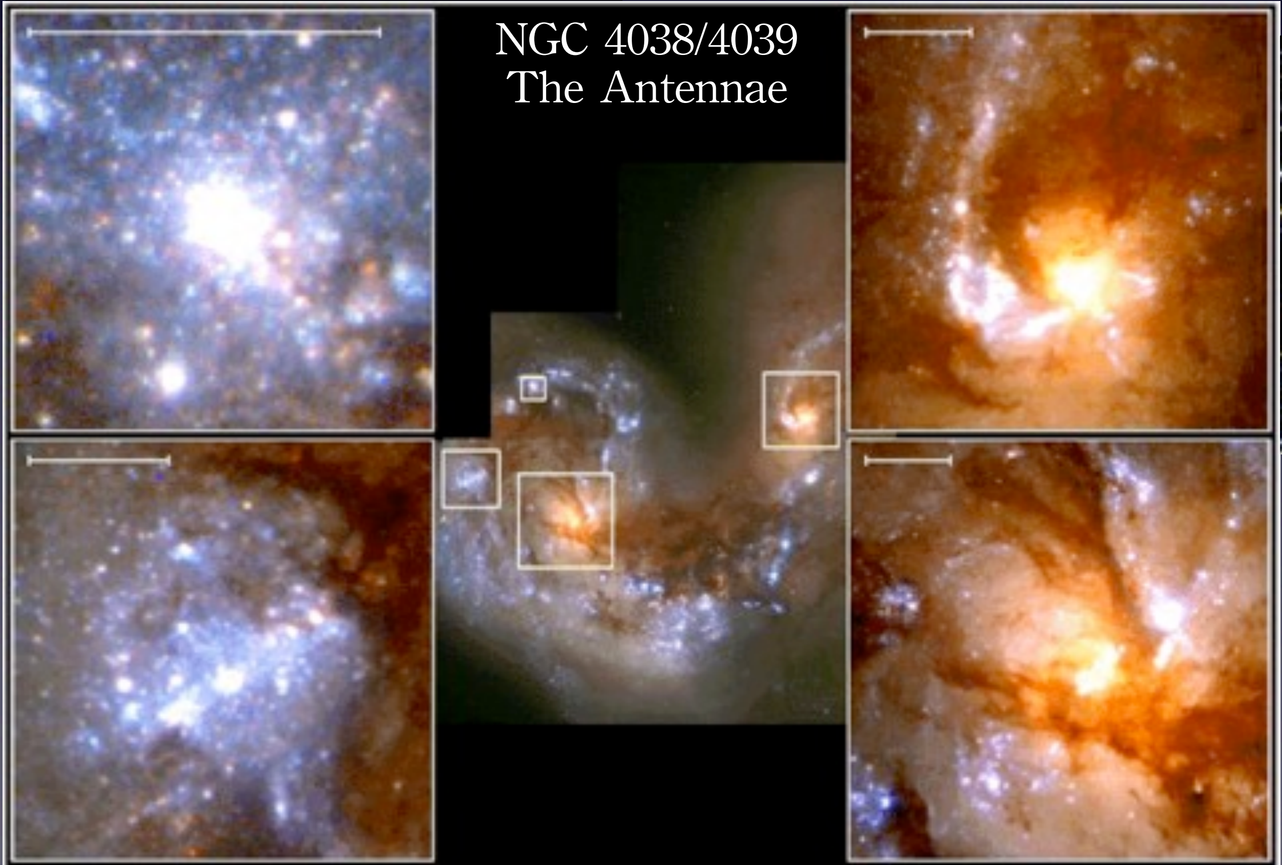
LIRGs: good laboratories to study SSCs



A pioneering discovery from the Hubble Space Telescope

Host hundreds to thousands of SSCs

SSCs are found whenever there is strong SF activity



Motivation ...

	SSC	GC
Mass	$10^{4-7}\ \mathrm{M}_\odot$	$10^{3.5-6}\ \mathrm{M}_\odot$
Size	$\sim 3-5\,\mathrm{pc}$	$\sim 0.3-4\,\mathrm{pc}$
Density	$\sim 10^4\ \mathrm{M}_\odot \mathrm{pc}^{-3}$	$10^{-1}-10^{4.5}$
Age	$3-100\,\mathrm{Myr}$	$10-12\,\mathrm{Gyr}$

Motivation ...

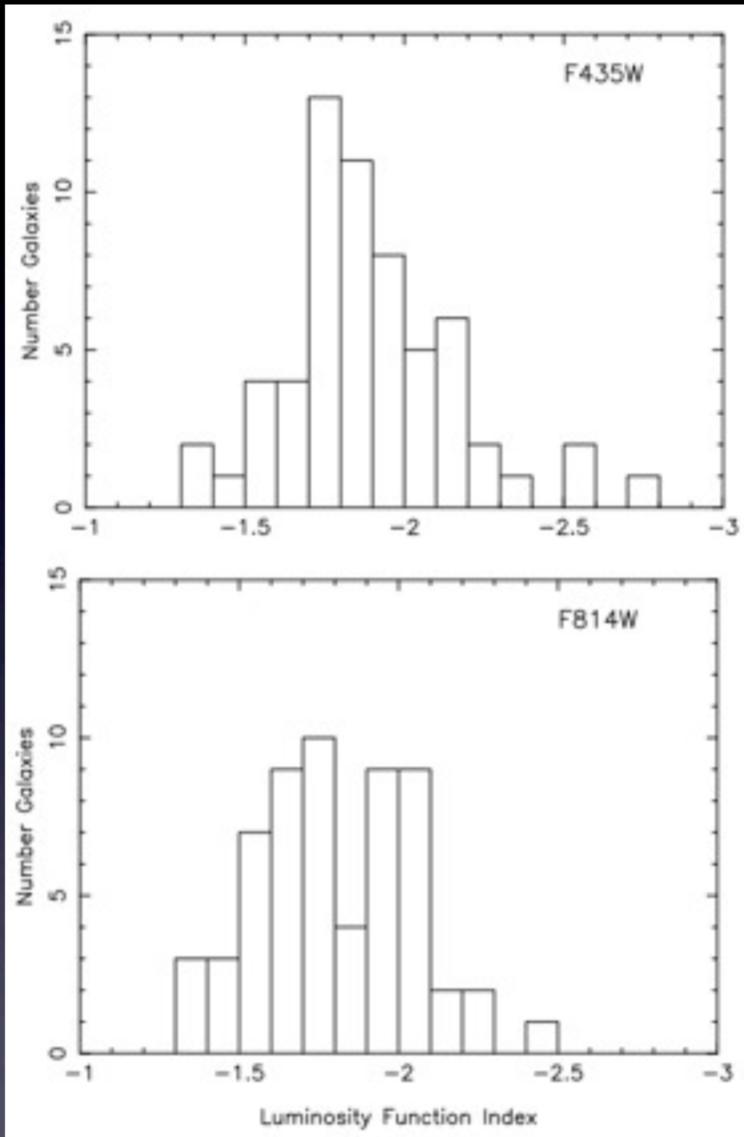
Starbursts
Interacting LIRGs

↑

The role(s) of the star cluster host galaxies in the cluster formation, evolution and disruption mechanisms?

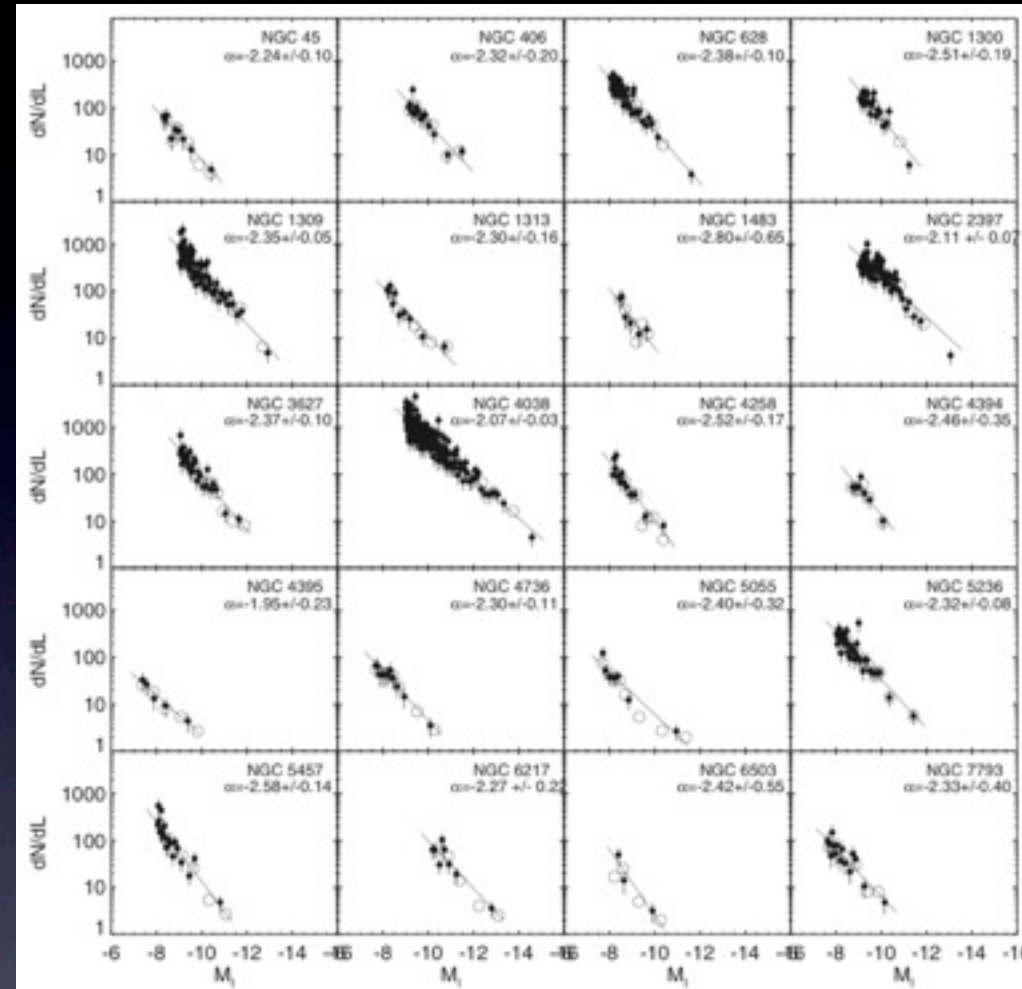
1. Star cluster luminosity functions

Vavilkin 2011



- 87 LIRGs in the HST-GOALS sample
- Luminosity distance in between ~ 35 - 200 Mpc
  $\log{(L_{IR}/L_{\odot})} > 11.4 \Rightarrow \mathrm{SFR} > 44\, M_{\odot} yr^{-1}$
- median: 1.86+/-0.27 (F435W)
  1.77+/-0.24 (F814W)

Whitmore+2014



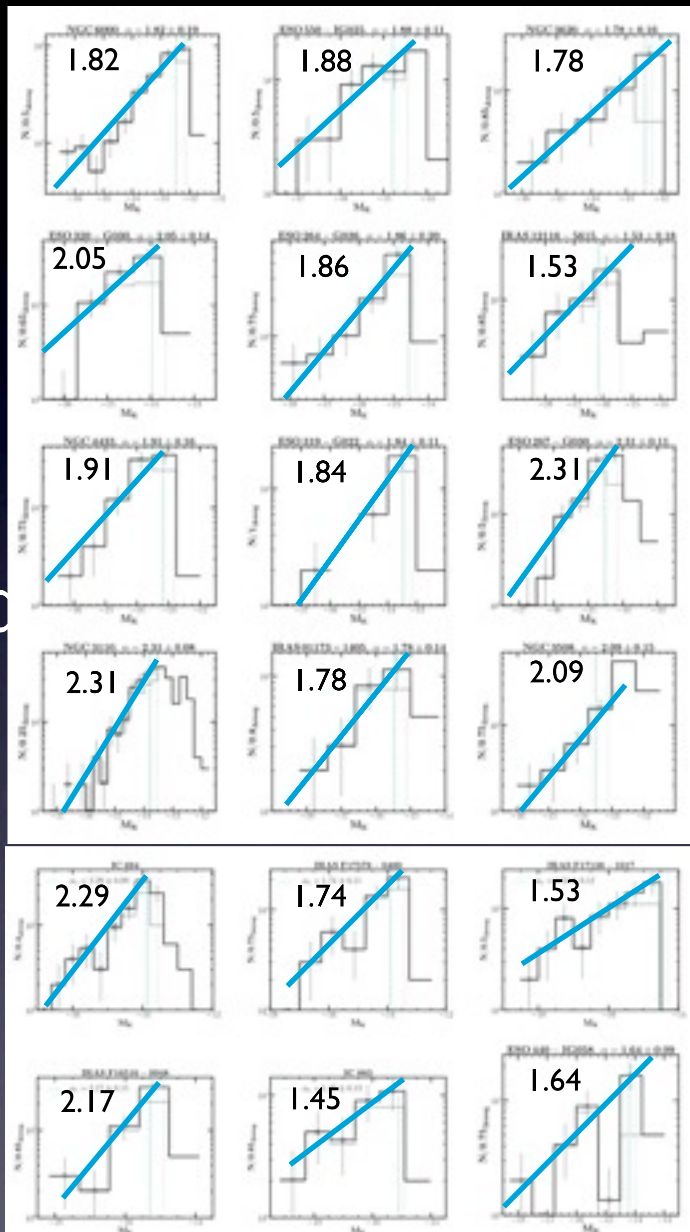
- 20 normal spiral star-forming galaxies from the Hubble Heritage
- Luminosity distance < 30 Mpc
  $\mathrm{SFR} < 2.43\, M_{\odot} yr^{-1}$
- average: 2.37+/-0.18 (F814W)

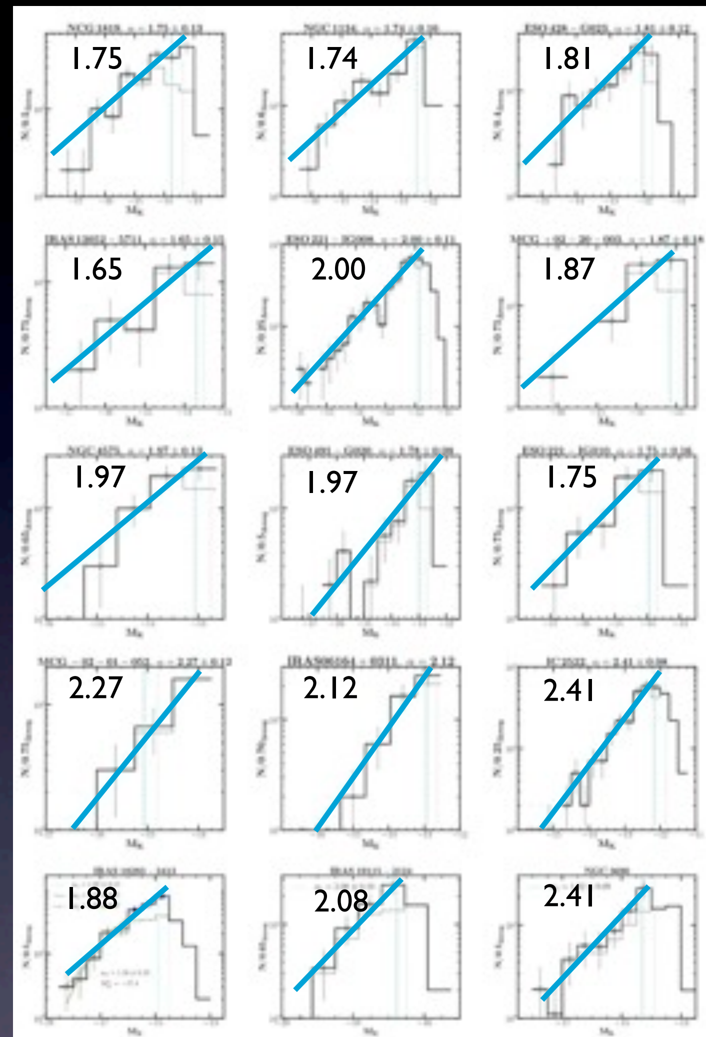
The difference in the power-law slope range:

- two distinct types of host galaxies
- blending effects?

1. The K-band SSC luminosity functions

Randriamanakoto+2013a, Randriamanakoto+, in prep

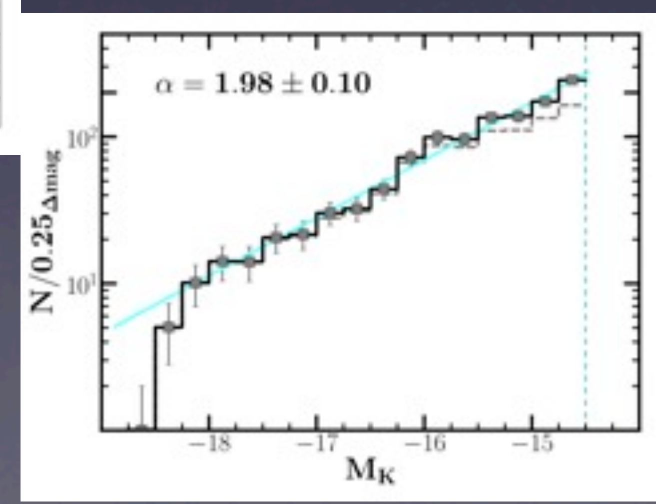




$$1.5 < \alpha < 2.4$$

	constant	variable
average	1.92	1.93
median	1.86	1.88
scatter	0.24	0.26

The whole SSC sample with a completeness level of -14.5 mag:



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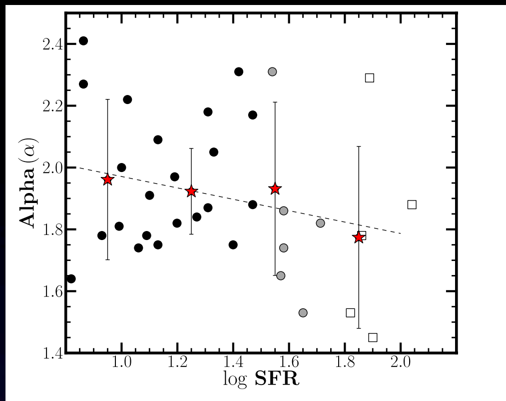


A weak correlation
r = - 0.25 +/-0.15

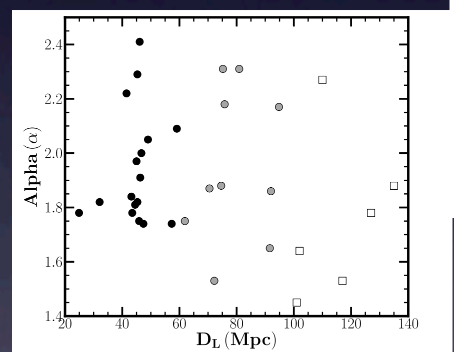
From the binned data points:
r = - 0.67 +/-0.21

	constant	variable
average	1.92	1.93
median	1.86	1.88
scatter	0.24	0.26

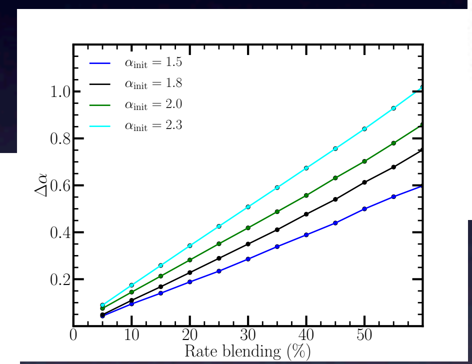
Vavilkin 2011
Miralles-Caballero+2011
Adamo+2010, 2011

$$30 \lesssim D_L\,(Mpc) \lesssim 200$$

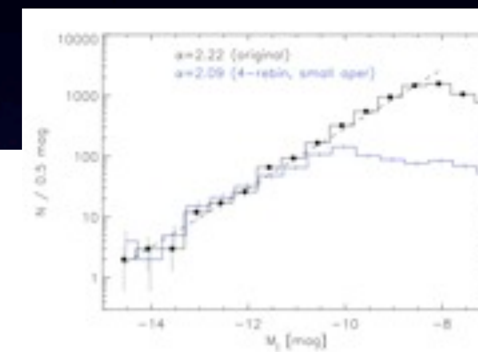
The effects of blending on the SSC LFs:



Correlation search



MC simulations



Redshifted Antennae

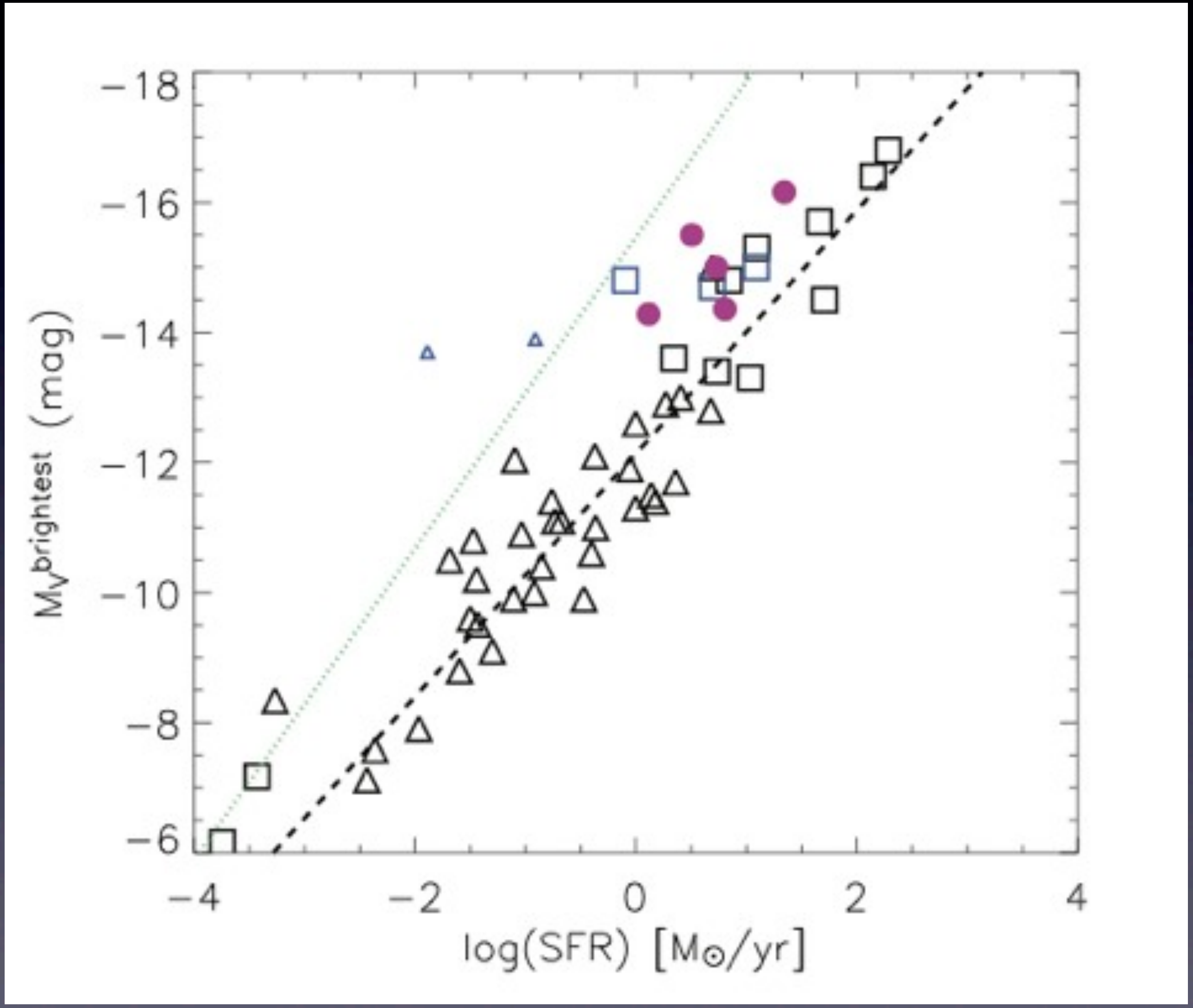
The effects should not be significant for targets closer than ~100 Mpc.

However, use the smallest aperture size to recover the intrinsic SSC counts (see also Bastian+2014).

2. Magnitude of the brightest cluster vs. log SFR

Weidner+ 2004
Bastian 2008,
Adamo+2011

$$M_V^{brightest} \sim -1.87(\pm 0.06) \times \mathrm{SFR}$$



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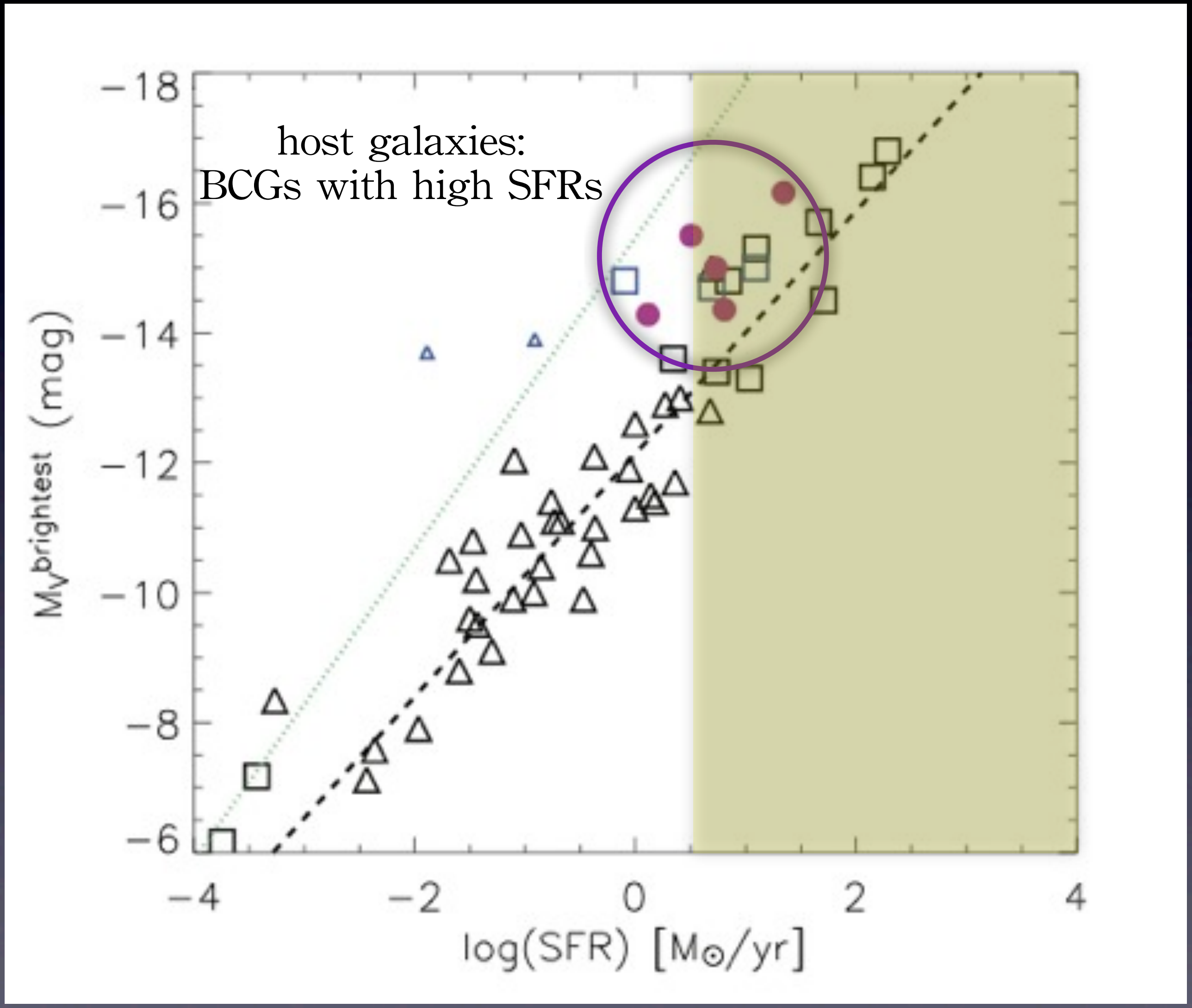
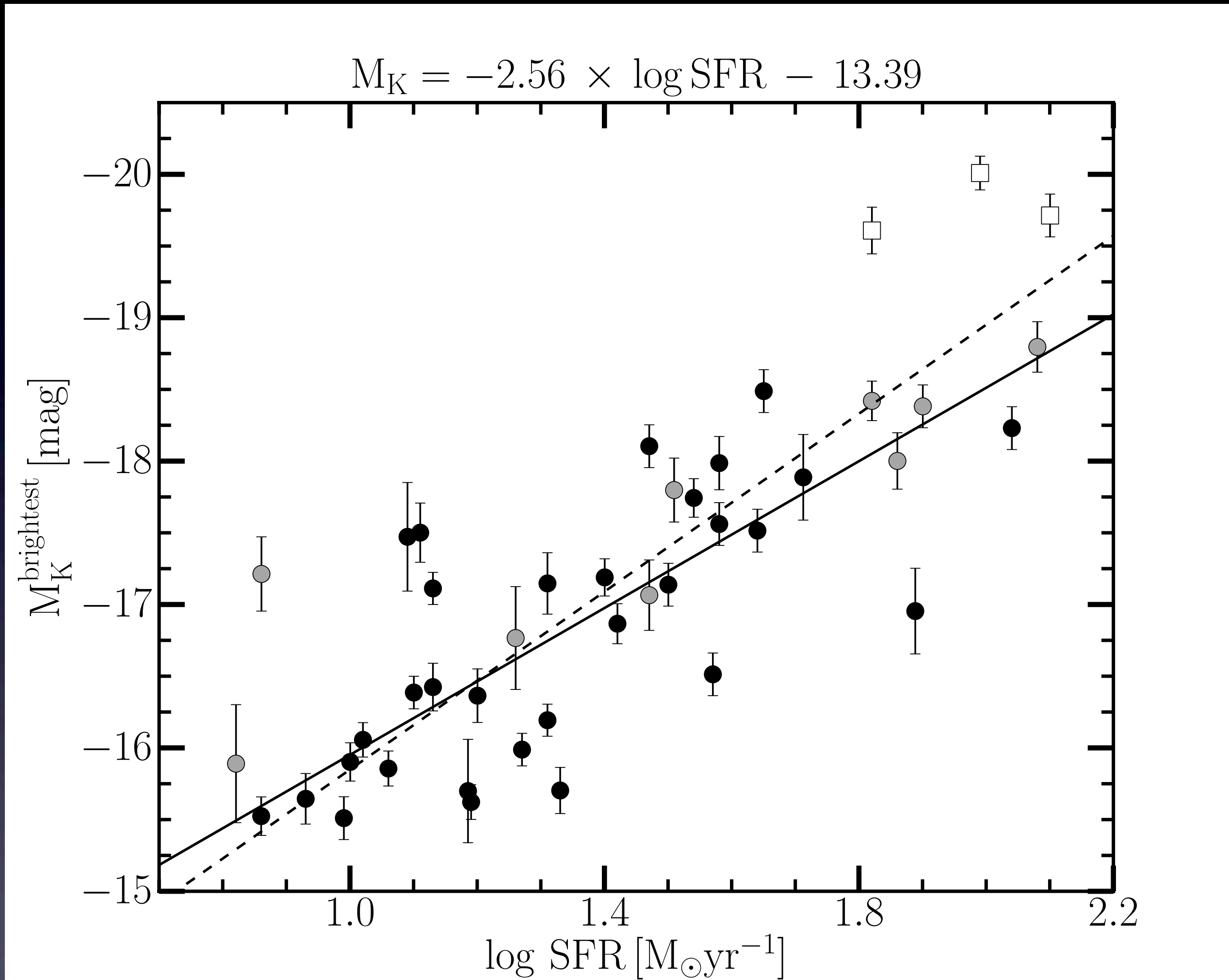


Does the relation still hold at larger SFR levels?

i.e. by considering brightest clusters hosted by galaxies with extreme environments

2. The brightest SSC NIR-mag vs SFR relation

Randriamanakoto+2013b



- SSC selection
- Blending
- SSCs vs foreground stars

Table 4.1: The different slopes and χ^2 values of the relation

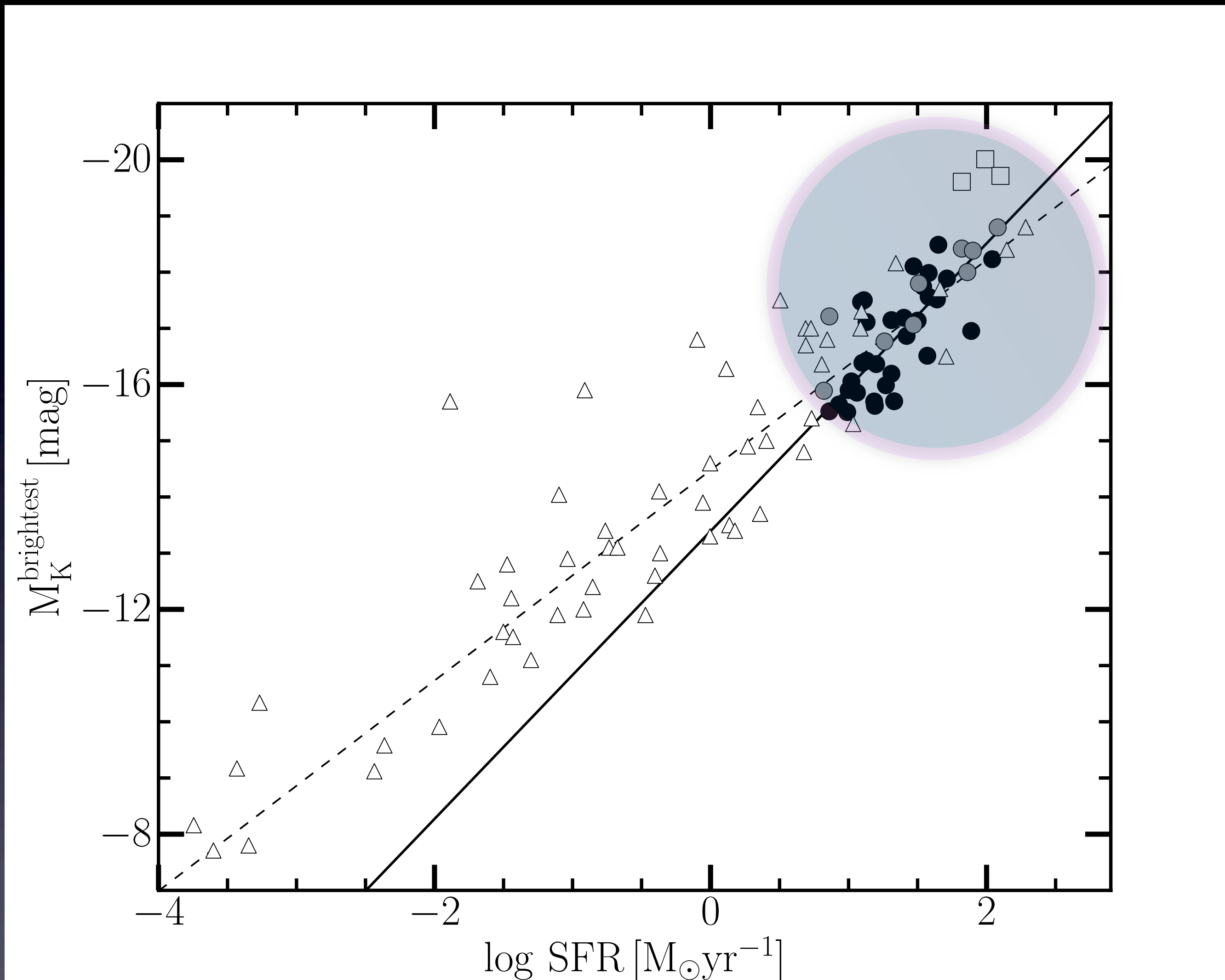
D_L^{cutoff} (Mpc) (1)	# data (2)	slope (3)	χ^2_{red} (4)
210	43	-3.10 ± 0.06	17.53
200	41	-2.72 ± 0.07	15.16
150	**40**	$\mathbf{-2.56 \pm 0.07}$	**13.27**
130	38	-2.56 ± 0.07	14.03
110	36	-2.51 ± 0.07	14.63
100	31	-2.52 ± 0.08	15.49
90	28	-2.49 ± 0.08	13.83
80	27	-2.50 ± 0.09	14.38
70	19	-1.89 ± 0.11	17.24

Notes. Column 1: the distance cutoff; Column 2: the number of targets with distances $< D_L^{cutoff}$; Columns 3 & 4: the resulting slope and χ^2 from the linear fits to the relation. The row with bold texts corresponds to the best fit where $D_L^{cutoff} = 150\,\mathrm{Mpc}$.

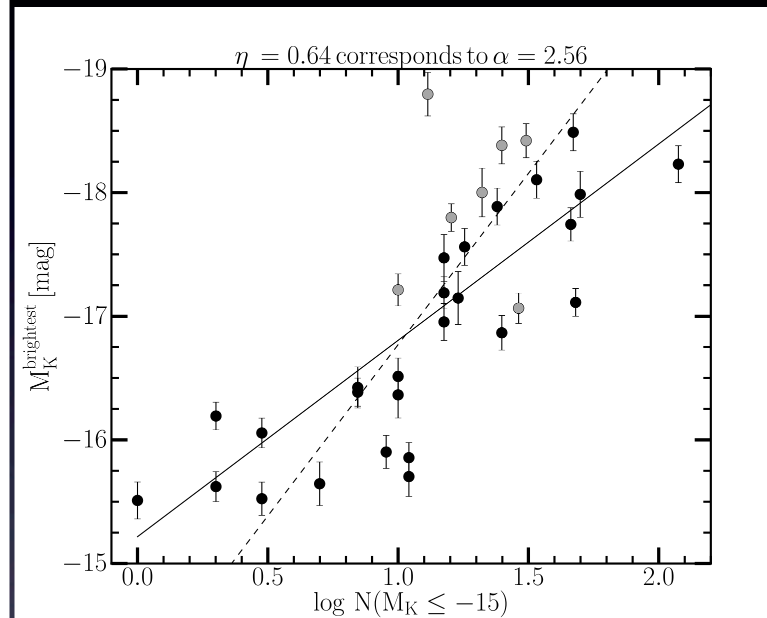
- r = 0.50 +/-0.02
- a scatter of 0.62mag (1mag in the optical relation, Larsen 2002)

2. The brightest SSC NIR-mag vs SFR relation

Randriamanakoto+2013b



$V - K \sim 2$



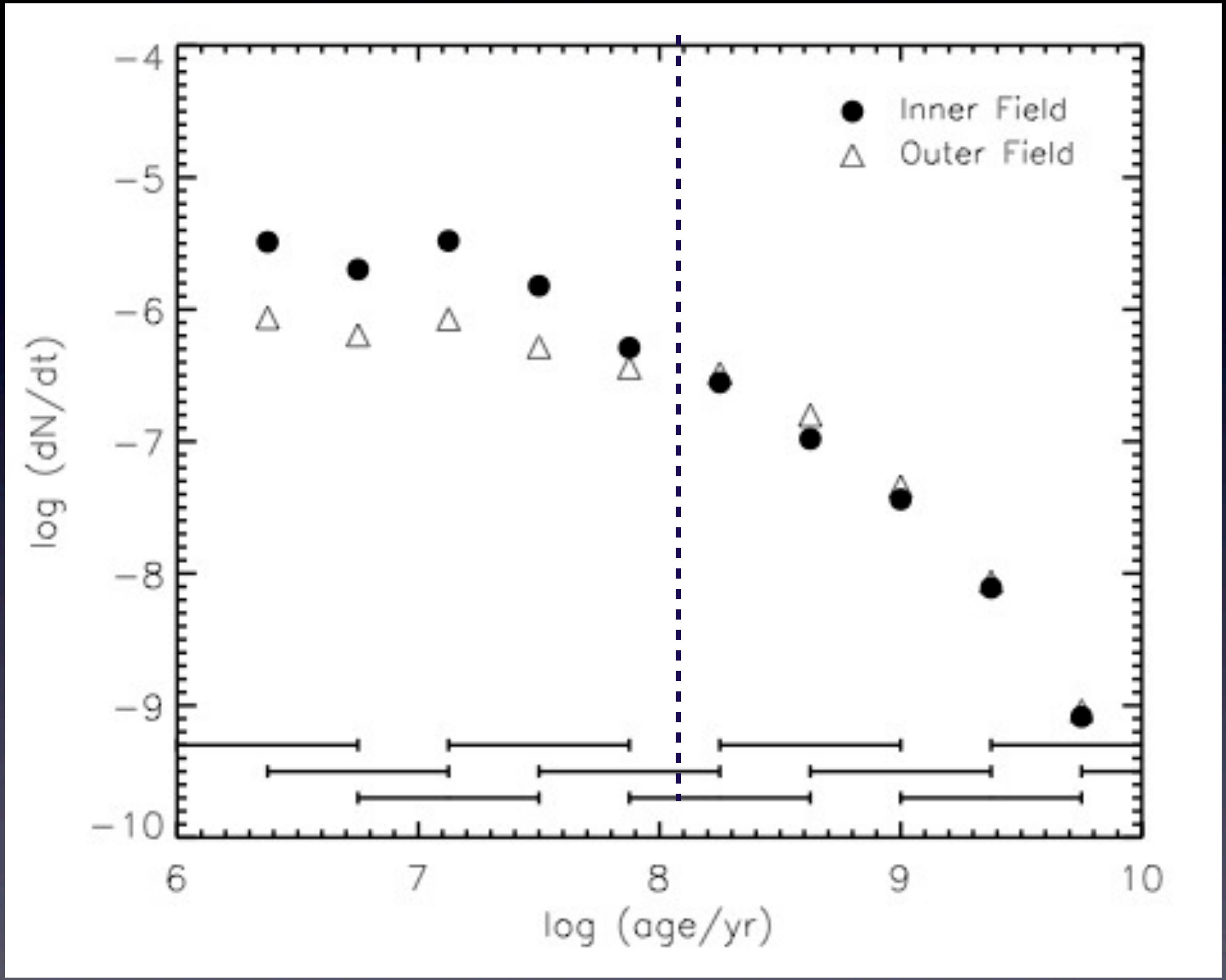
A size-of-sample effect

Physical truncation at high masses
=> tight scatter of the relation

3. The star cluster frequency

(number of clusters per time interval)

M83, Bastian+2012



$$dN/d\tau \sim t^{-\zeta}$$

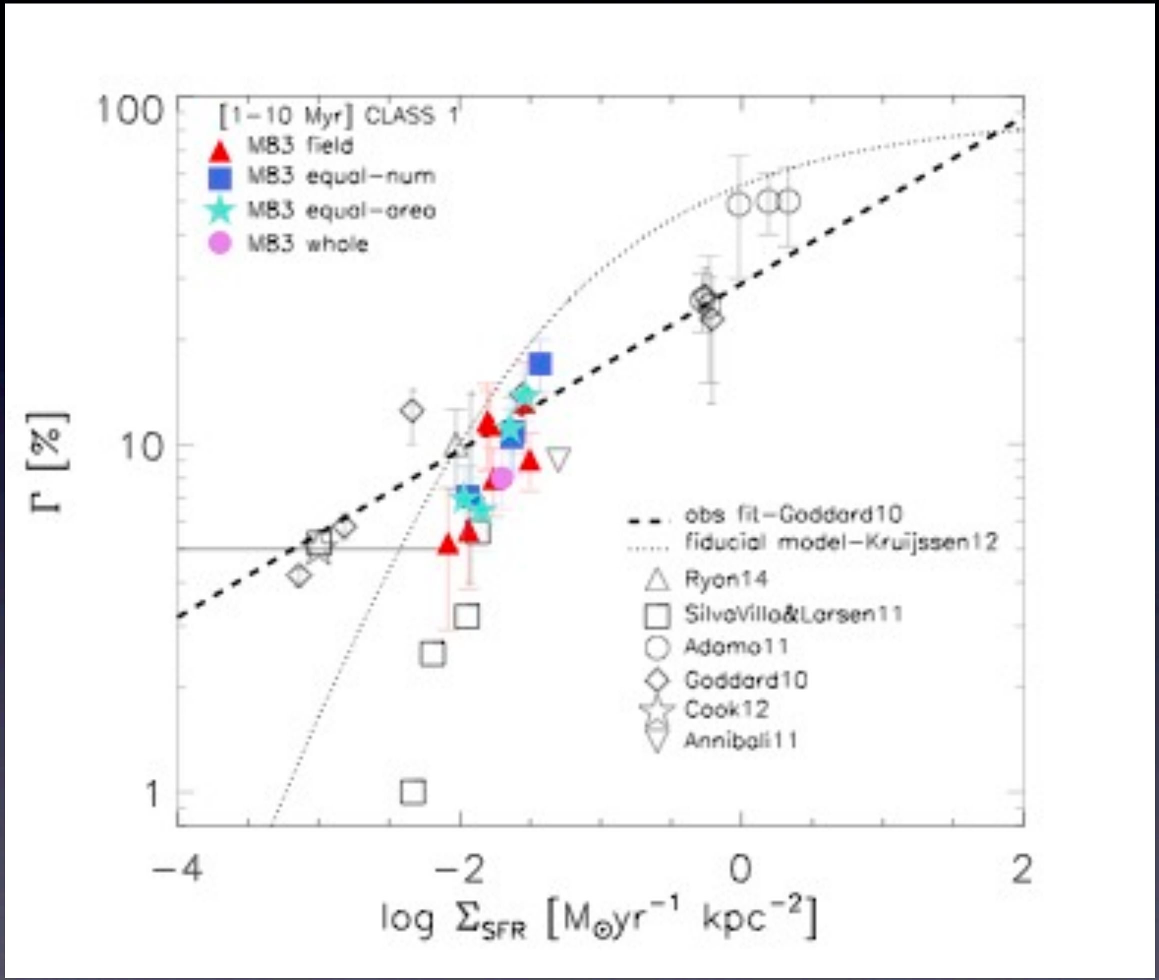
- Constant disruption: $\zeta = 1$
- Mass-dependent: $\zeta \neq 1$

What is the role of the environment?

4. The star cluster formation efficiency

(the fraction of SF happening in bound SCs)

Adamo+2015



$$\Gamma(\%) = \frac{\mathrm{CFR}}{\mathrm{SFR}} \times 100$$

Bastian 2008

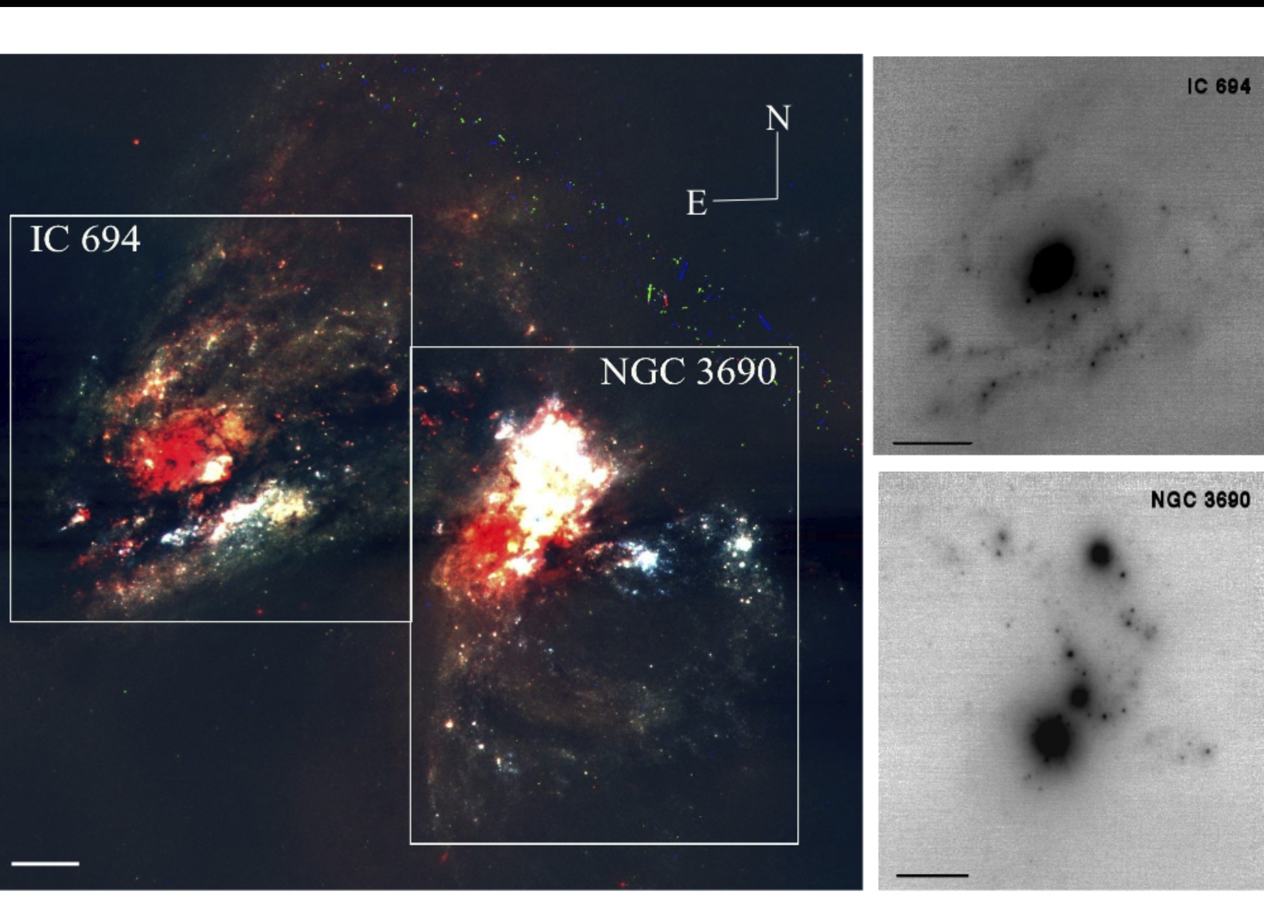
A reflection of the CFE - gas density relation

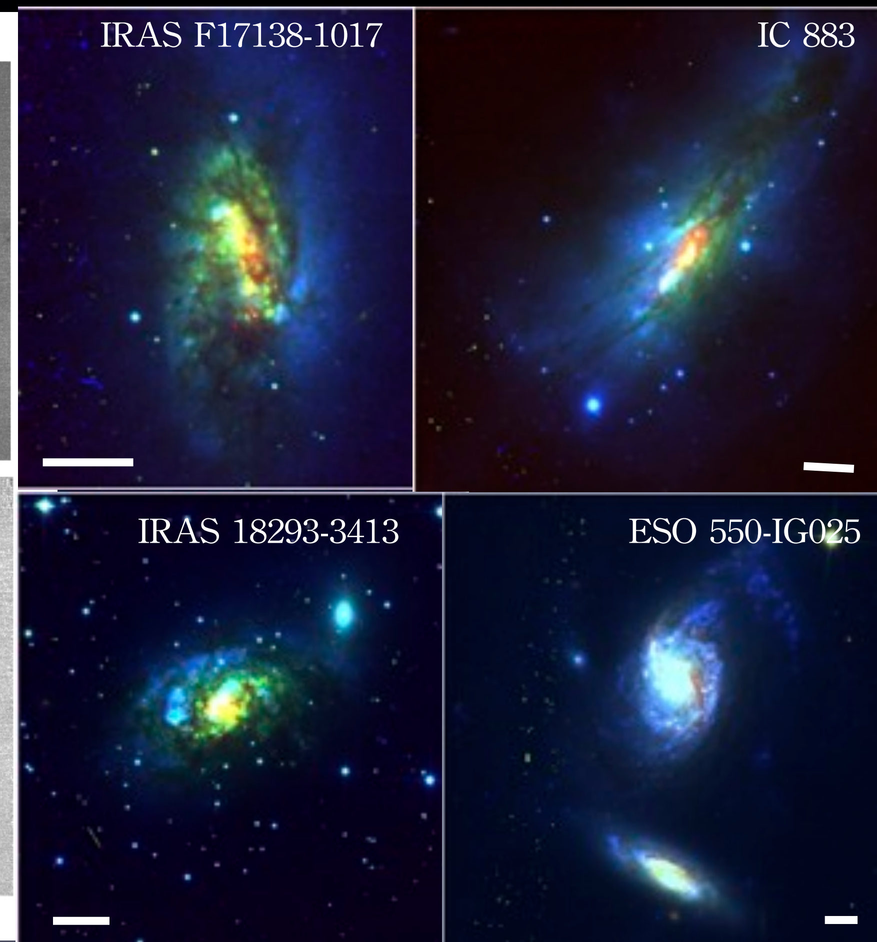
=> high SFE environments produce more GMCs

=> more stars are expected to form in bound stellar clusters

3 & 4. Properties of optically-selected SSCs

Randriamanakoto+, in prep; Vaisanen+, in prep





UBI-bands, HST/WFC3 UVIS (GOALS, PI: Evans)
K-band AO NIR imaging

BI-bands, HST/ACS (GOALS, PI: Bond)
K-band AO NIR imaging

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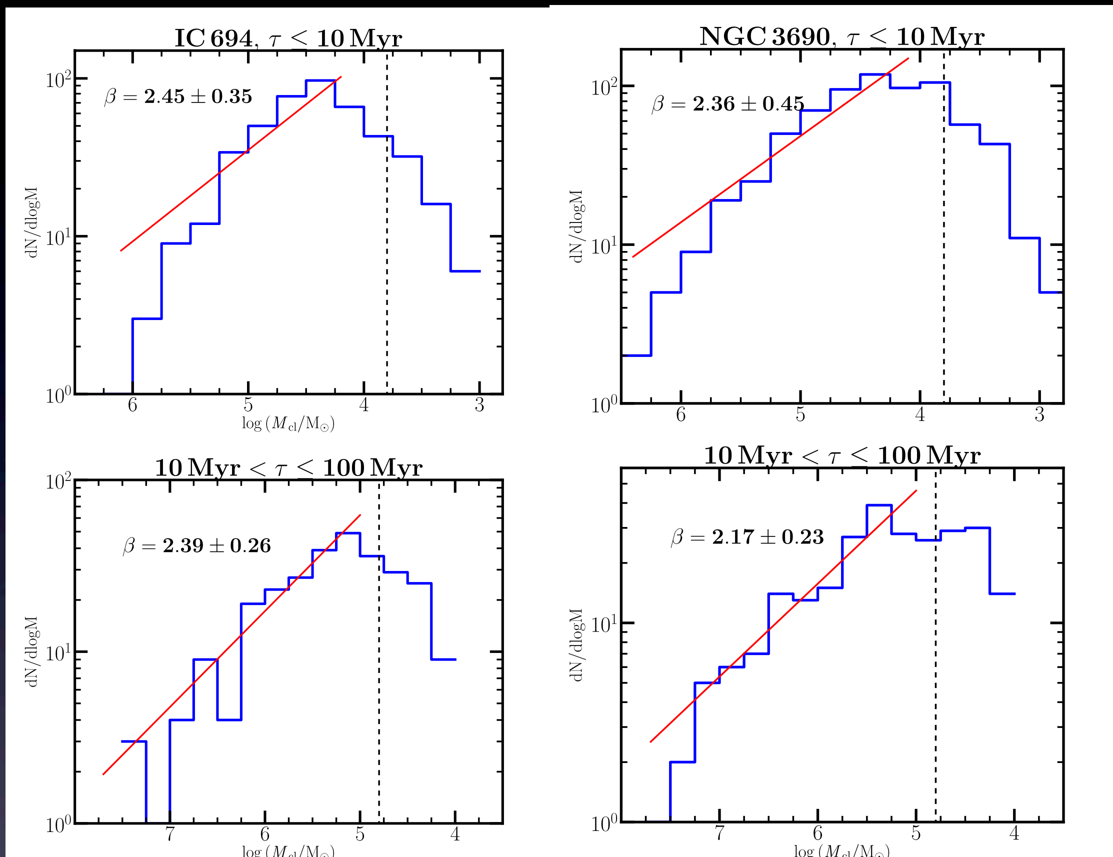

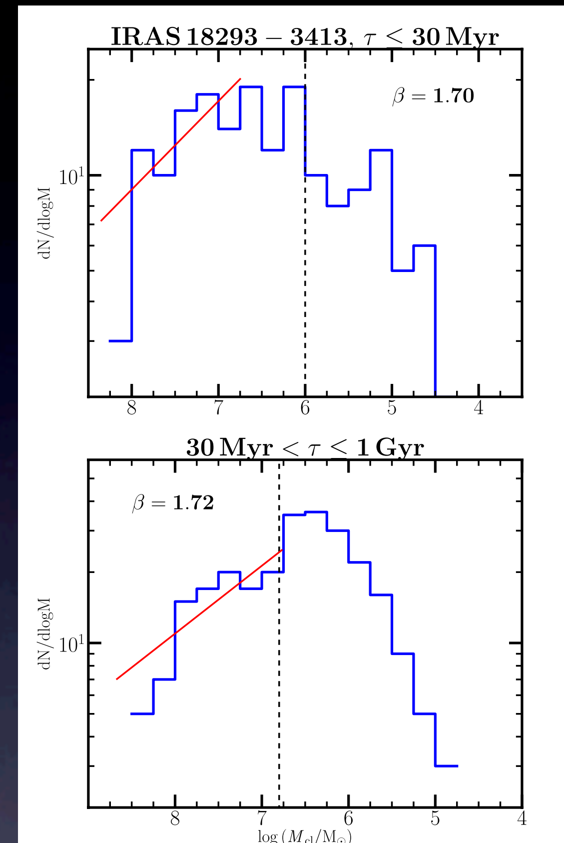

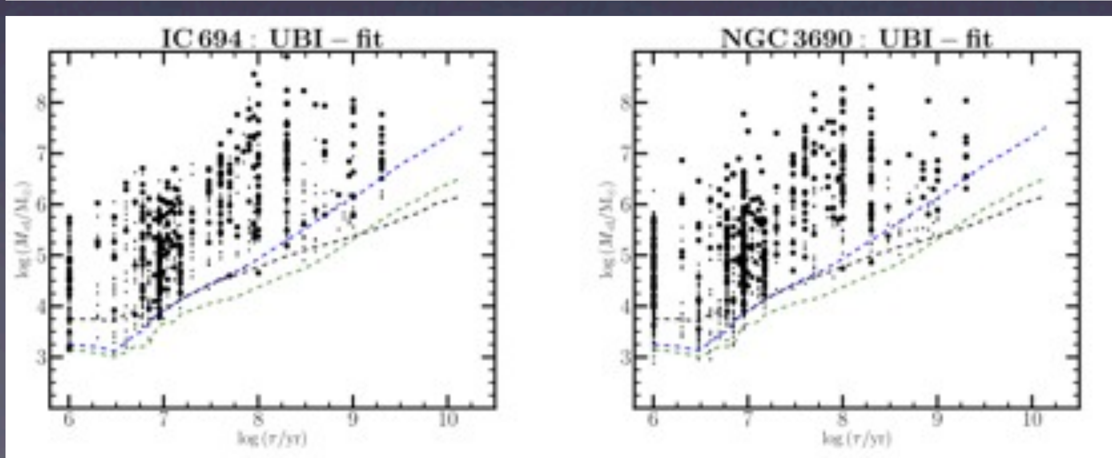

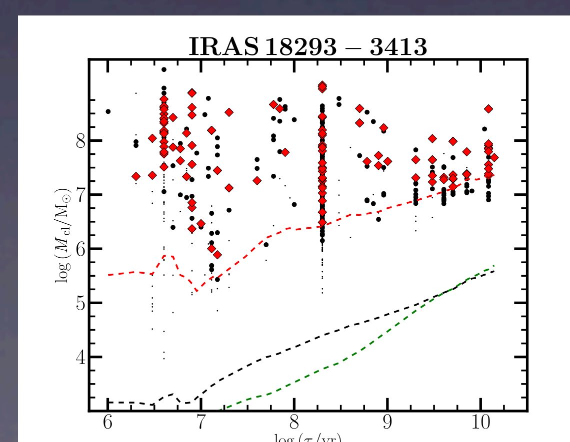

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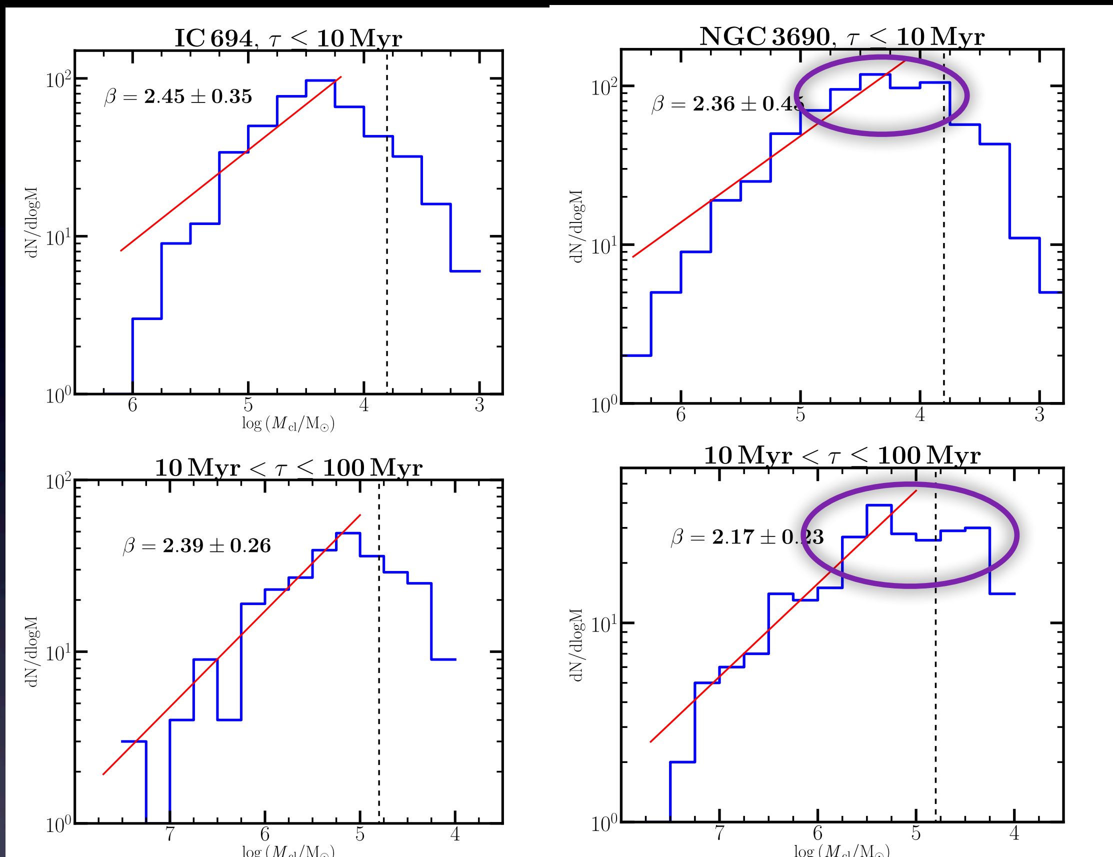
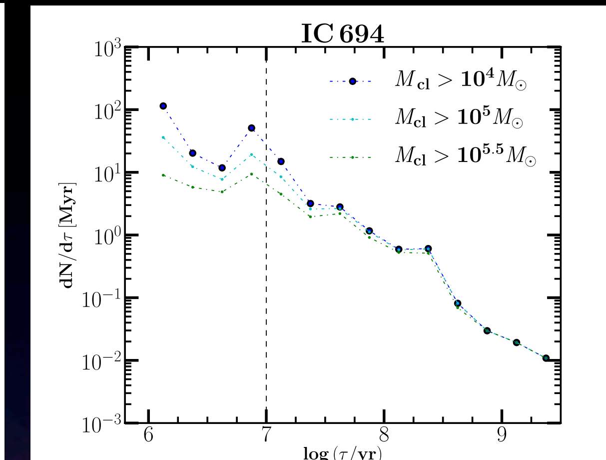
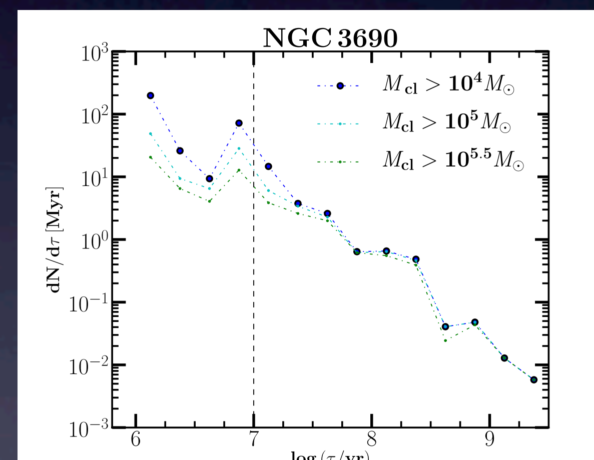




$\zeta = 1.50$

$\Gamma = 10\,\%$

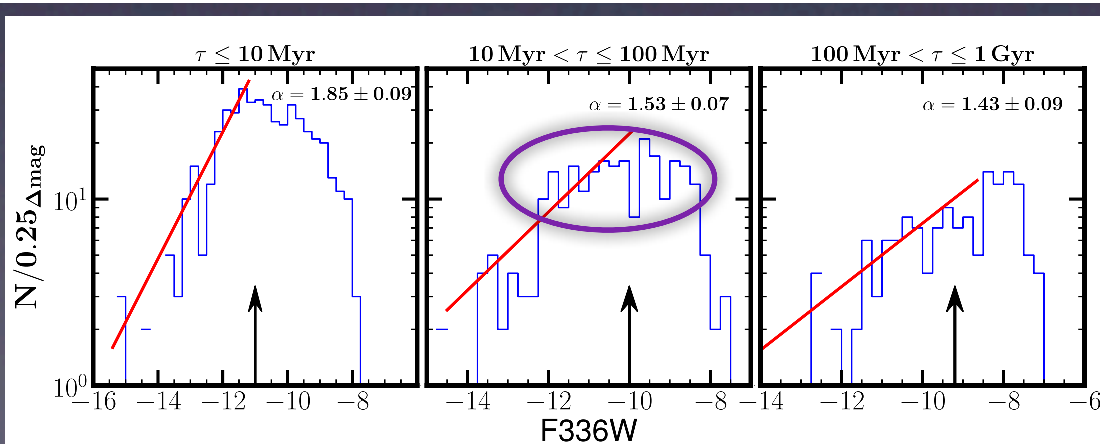
$SFR = 77 \pm 27\, M_\odot yr^{-1}$



$\zeta = 1.54$

$\Gamma = 16\,\%$

$SFR = 52 \pm 18\, M_\odot yr^{-1}$



$\Gamma = 12 \pm 2\,\%$

NGC 3256, an ongoing starburst merger

Goddard+ 2010

3 & 4. Properties of optically-selected SSCs

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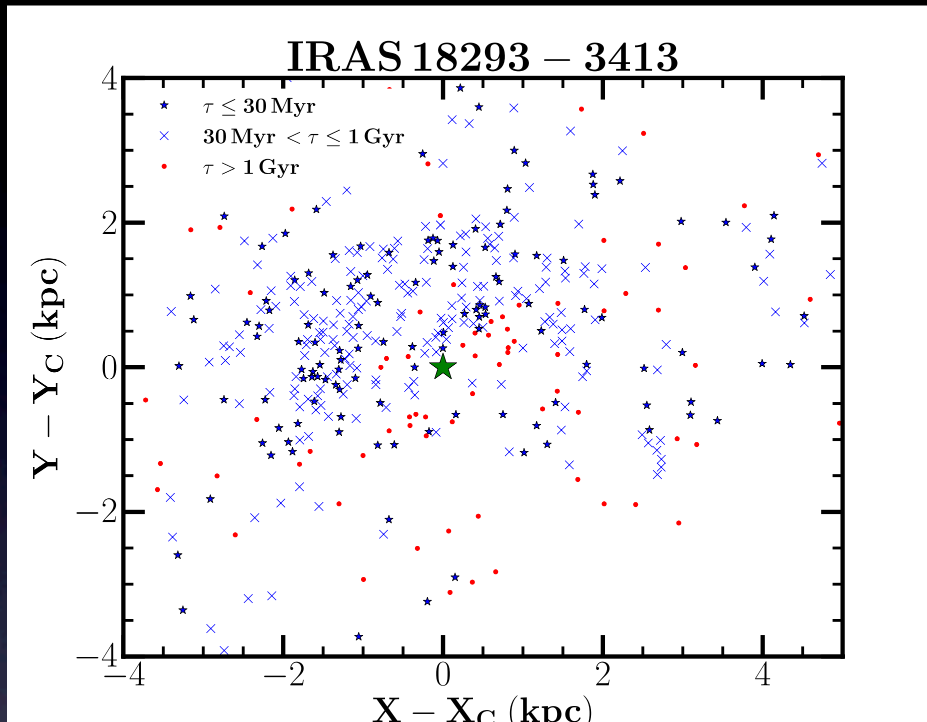
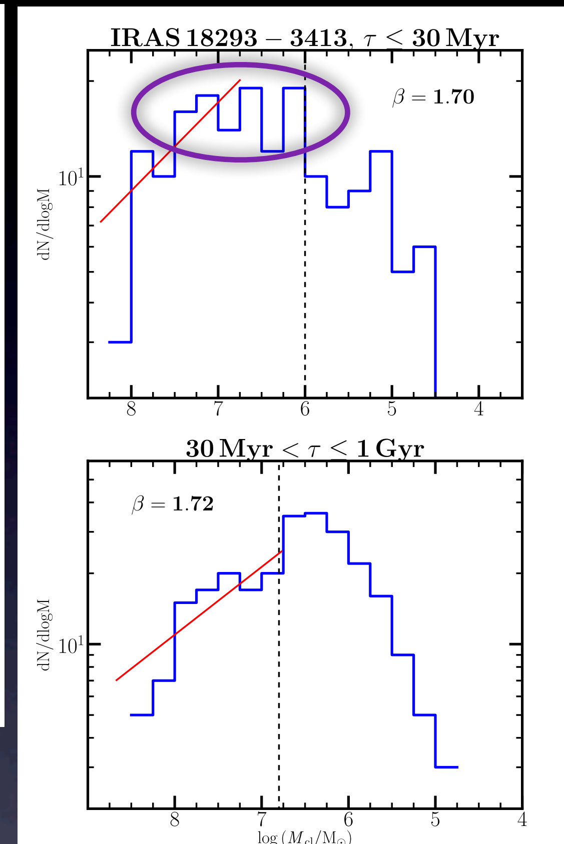
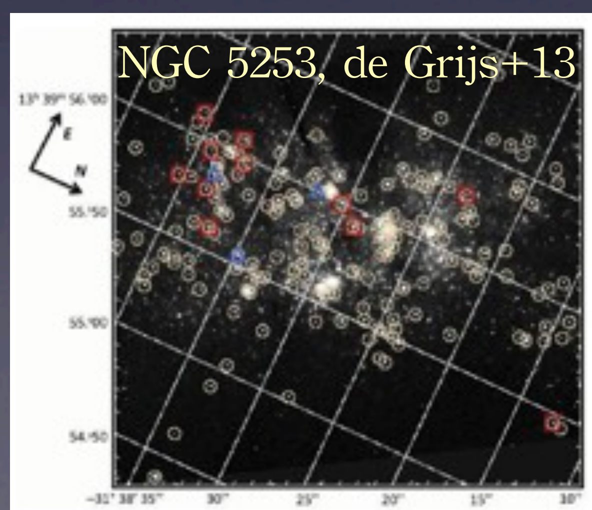




Turnover of
the mass function
in all age bins

mass-dependent
dissolution of clusters
in a rapid timescale

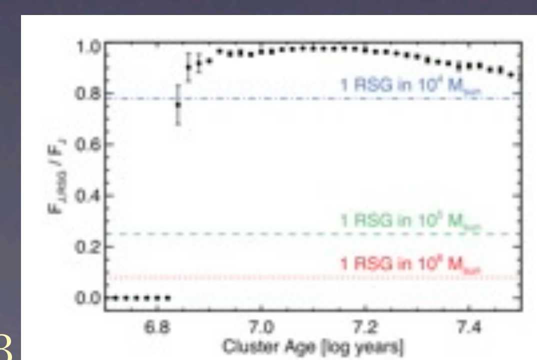
Similar cases:



CAUTION: BIK-filters only

Stochastic effects due to RSGs and AGBs

Gazak+13



Summary, Conclusion & Future directions

SUNBIRD is an ongoing survey of nearby starbursts and LIRGs.

SSC LF power-law slopes of intensely star-forming galaxies differ from those of more quiescent galaxies.

Size-of-sample effect is still the main driver of the NIR brightest cluster magnitude - SFR relation, though physical process should not be ruled out.

Cluster mass-dependent disruption mechanism for Arp 299 and with a rapid dissolution in the case of IRAS 18293-3413

=> High SFR host galaxies are good laboratory to study the effects of the environments on the star cluster formation, evolution and disruption.

How does the cluster disruption affect smaller scales of the galactic fields?

Where in the CFE - SFR density relation?