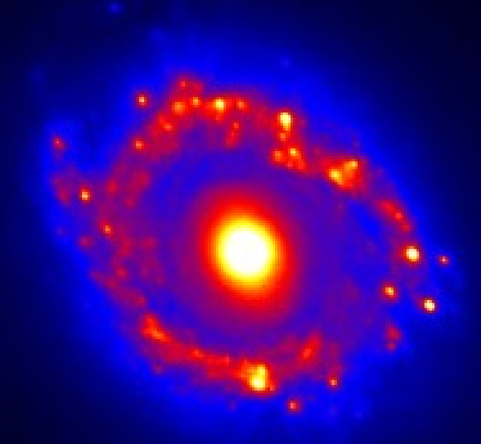
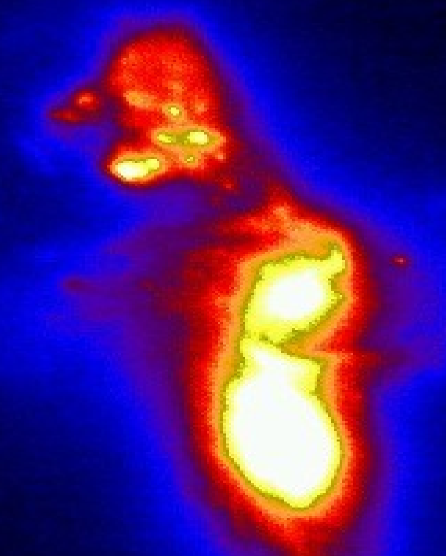
Super star clusters in interacting strongly star-forming galaxies





Petri Väisänen (SAAO / SALT)

Zara Randriamanakoto, Abiy Tekola, Rajin Ramphul, Alexei Kniazev, Sudhanshu Barway (SAAO / UCT)

Seppo Mattila, Jari Kotilainen, Erkki Kankare, Cristina Romero-Canizales (Turku / FINCA)

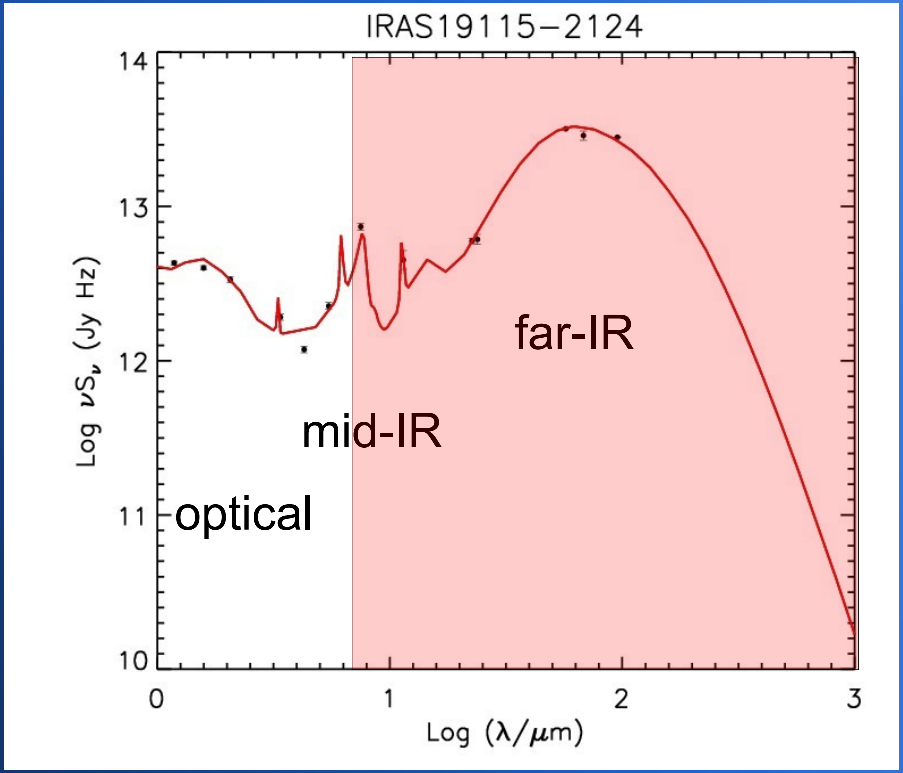
Stuart Ryder (Sydney / Gemini), Andres Escala (U. de Chile), Angela Adamo (MPIA), Miguel Perez-Torres (Granada)

Outline

- LIRGs
- Super Star Clusters
- Adaptive optics observations
- SSC luminosity functions
  and other characteristics
- Summary

LIRGs and ULIRGs

- (Ultra) Luminous IR galaxies: LIRGs and ULIRGs $>10^{11}$ and $> 10^{12}\ L_{\odot}$
- Sites of key processes:
  - Interactions and mergers
  - Starburst and AGN interplay, SMBH growth
  - Similar global levels of SF as in the high-z Universe



Haikko 2012

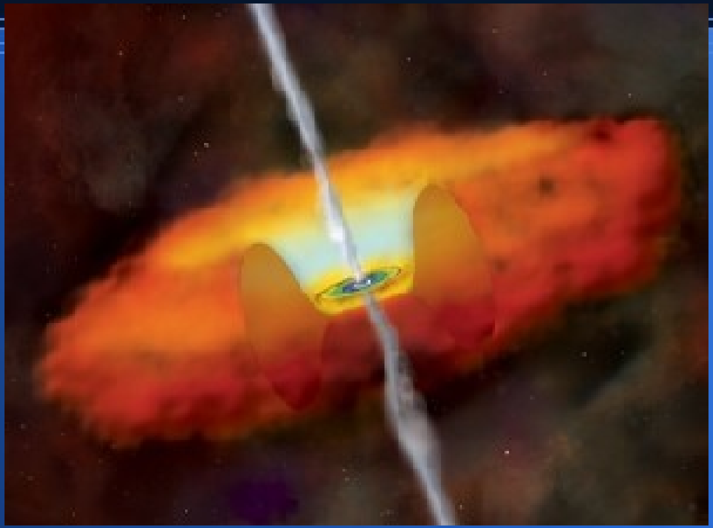
Merger sequence

- An evolutionary sequence – how is this happening exactly ?

gas spirals → starburst / ULIRG → obscured AGN → QSO → elliptical galaxy

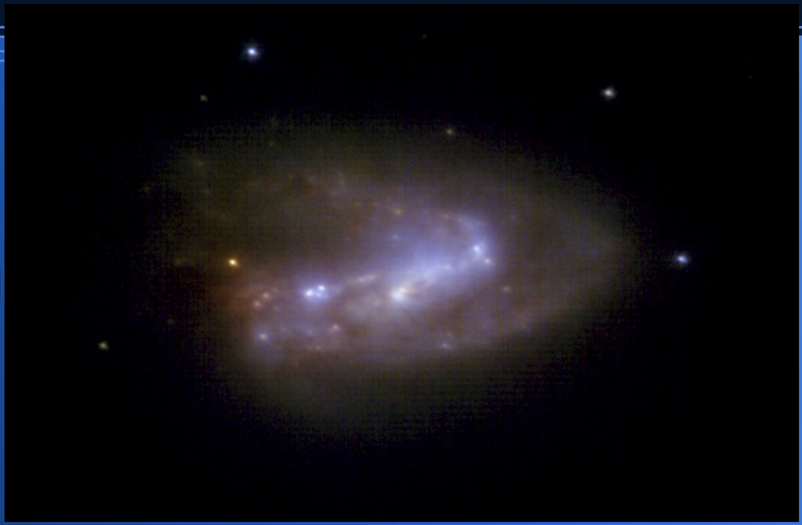
Many questions remain

- Interplay between AGN and star formation, what exactly triggers what? Are the evolutionary transitions causal or coincidental?
- How do the galactic outflows (feedback) affect the evolution and host properties?
- WHY are some galaxies LIRGs?
- And WHY are they not ULIRGs?
- Any relevance to the bigger picture?

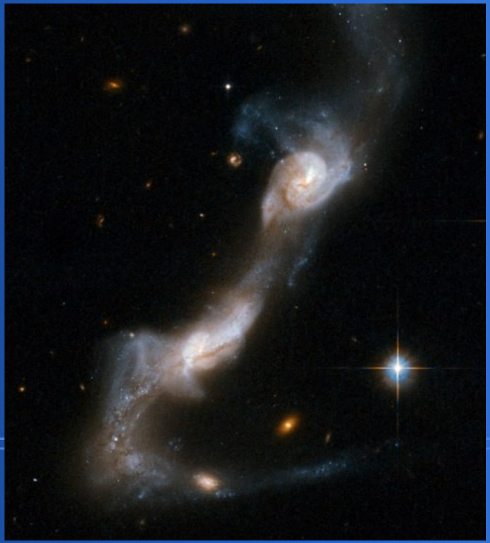


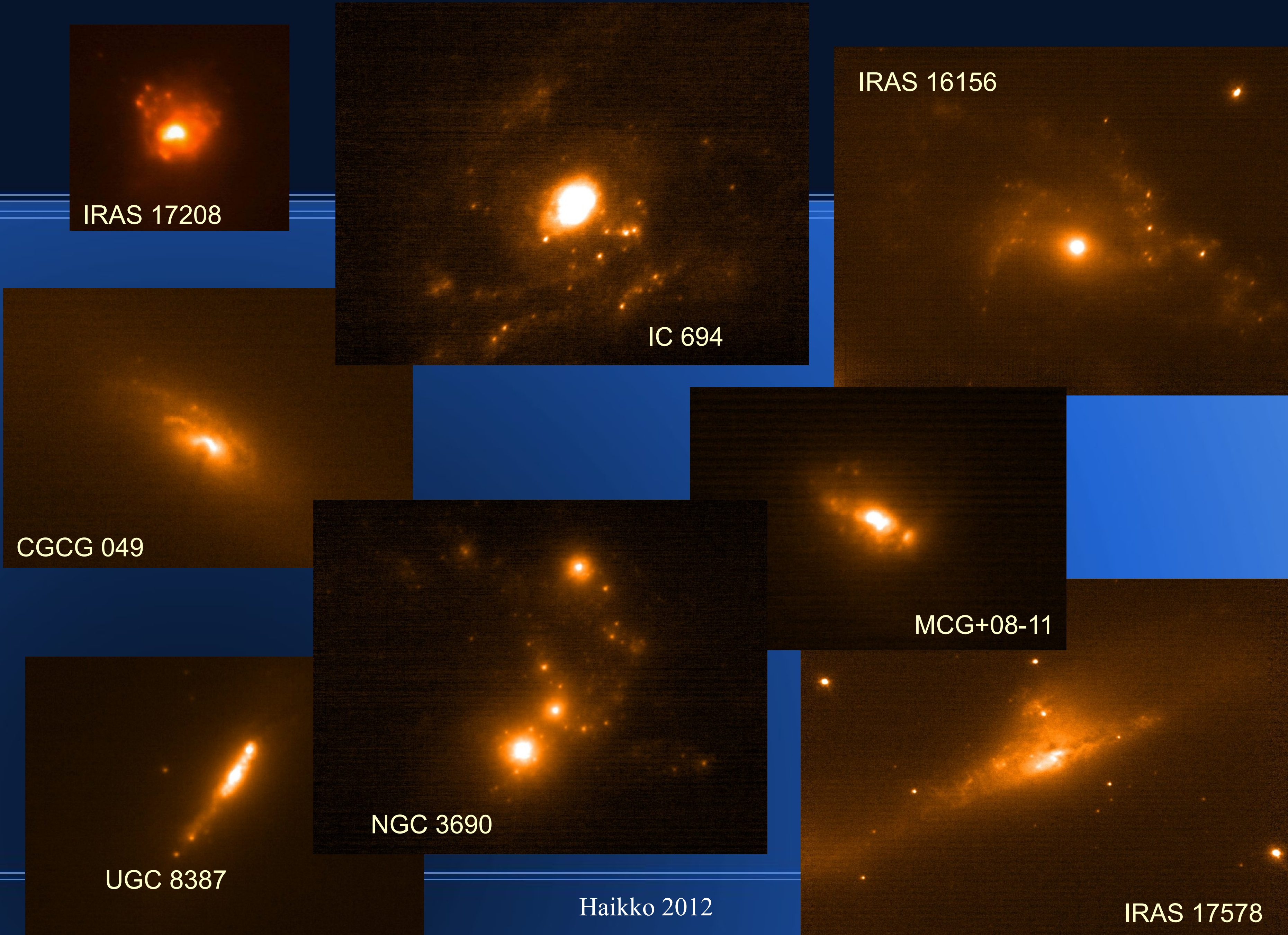
Haikko 2012

AO data of LIRGs



- VLT/NACO and Gemini/Altair NIR **adaptive optics** programs
  - High spatial resolution (~0.1”) K-band images of “LIRGs”
  - ~40 targets, mostly at 50-100 Mpc, strong AGN excluded, wide range of interaction stages
  - Data match very well optical HST/ACS LIRG imaging archival data
  - Complemented by archival Spitzer data and ground based spectroscopy SALT + some NIR IFU observations.

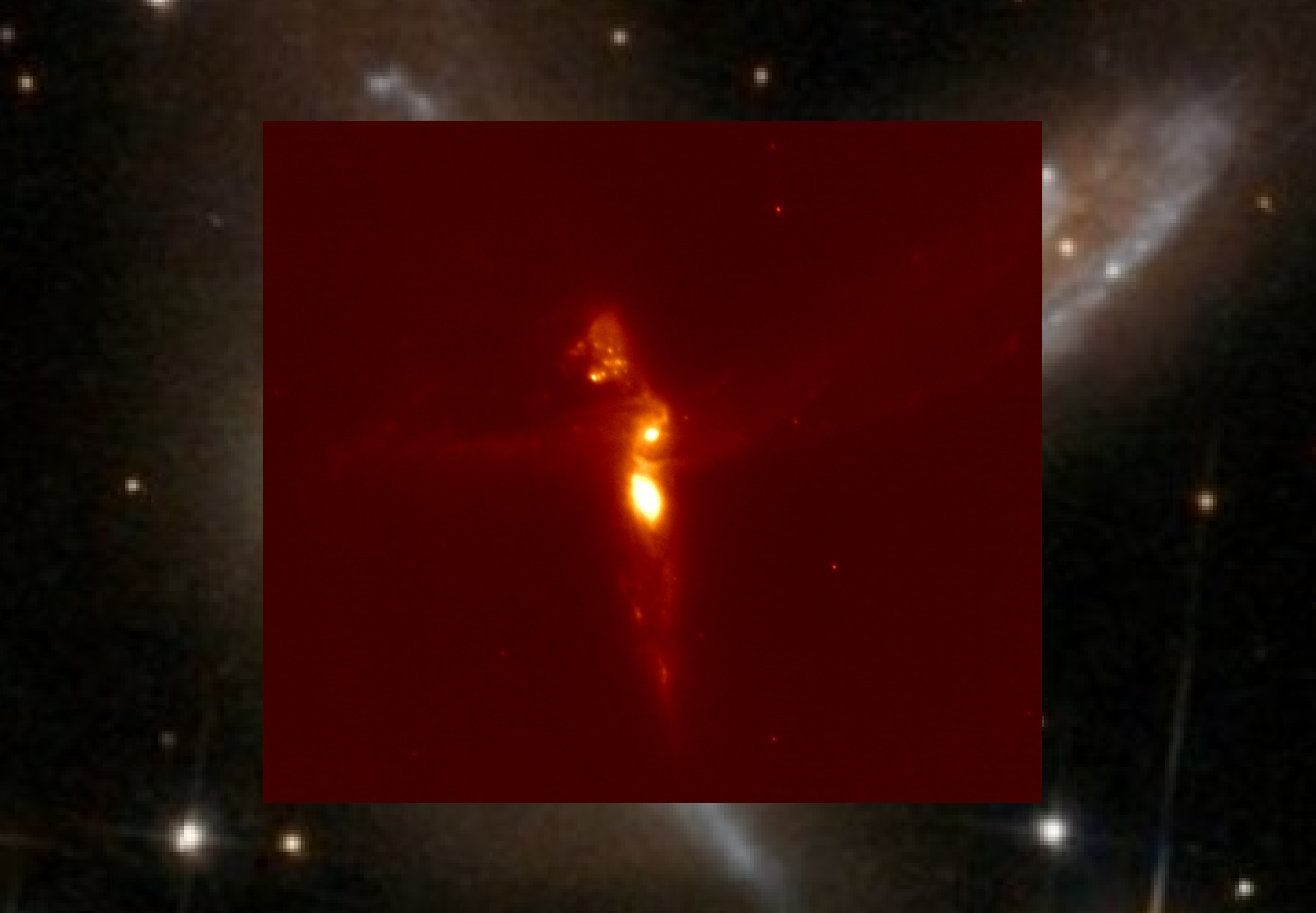


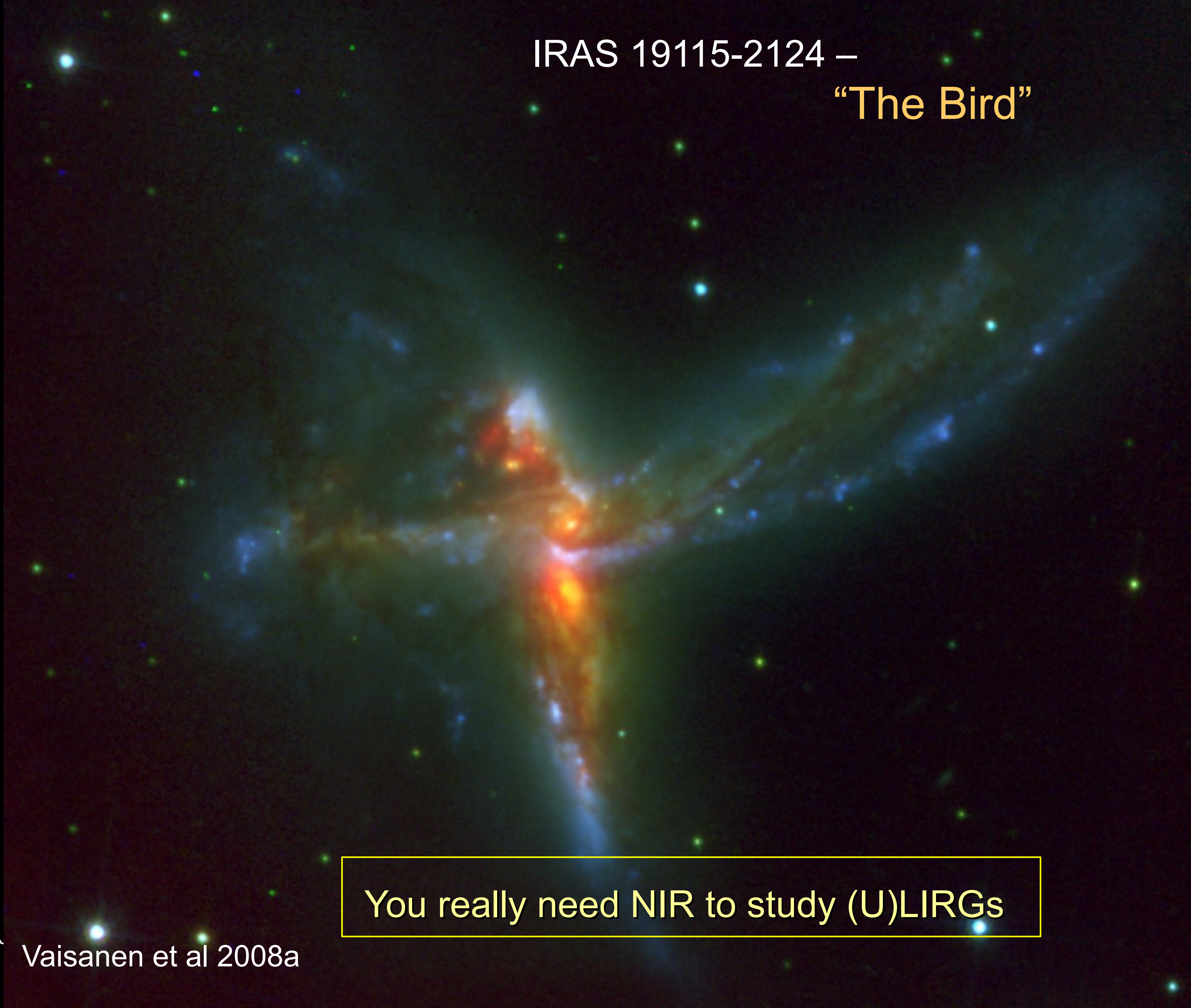

IRAS 17208
IC 694
IRAS 16156
CGCG 049
MCG+08-11
NGC 3690
UGC 8387
IRAS 17578

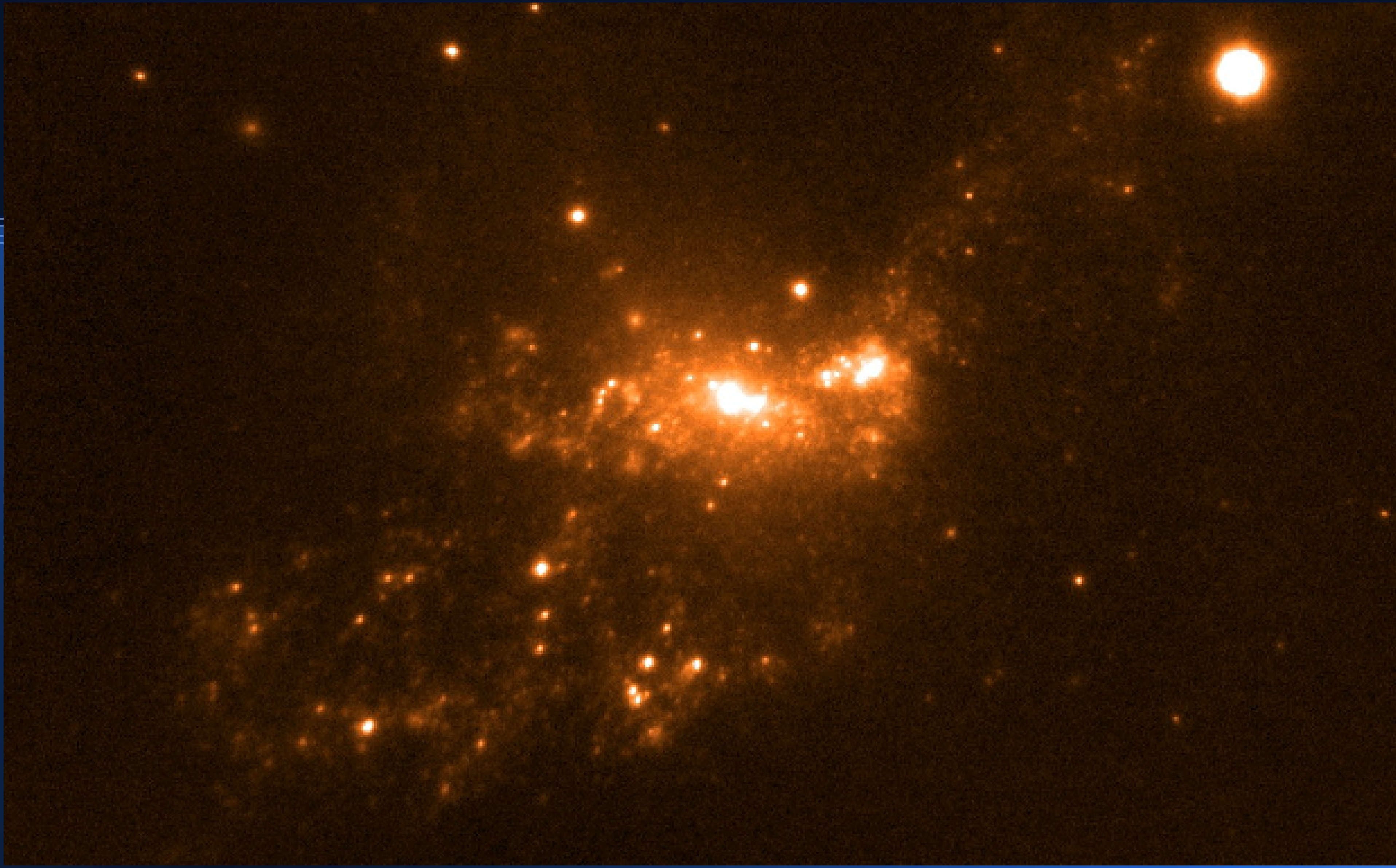
Haikko 2012


IRAS 19115-2124

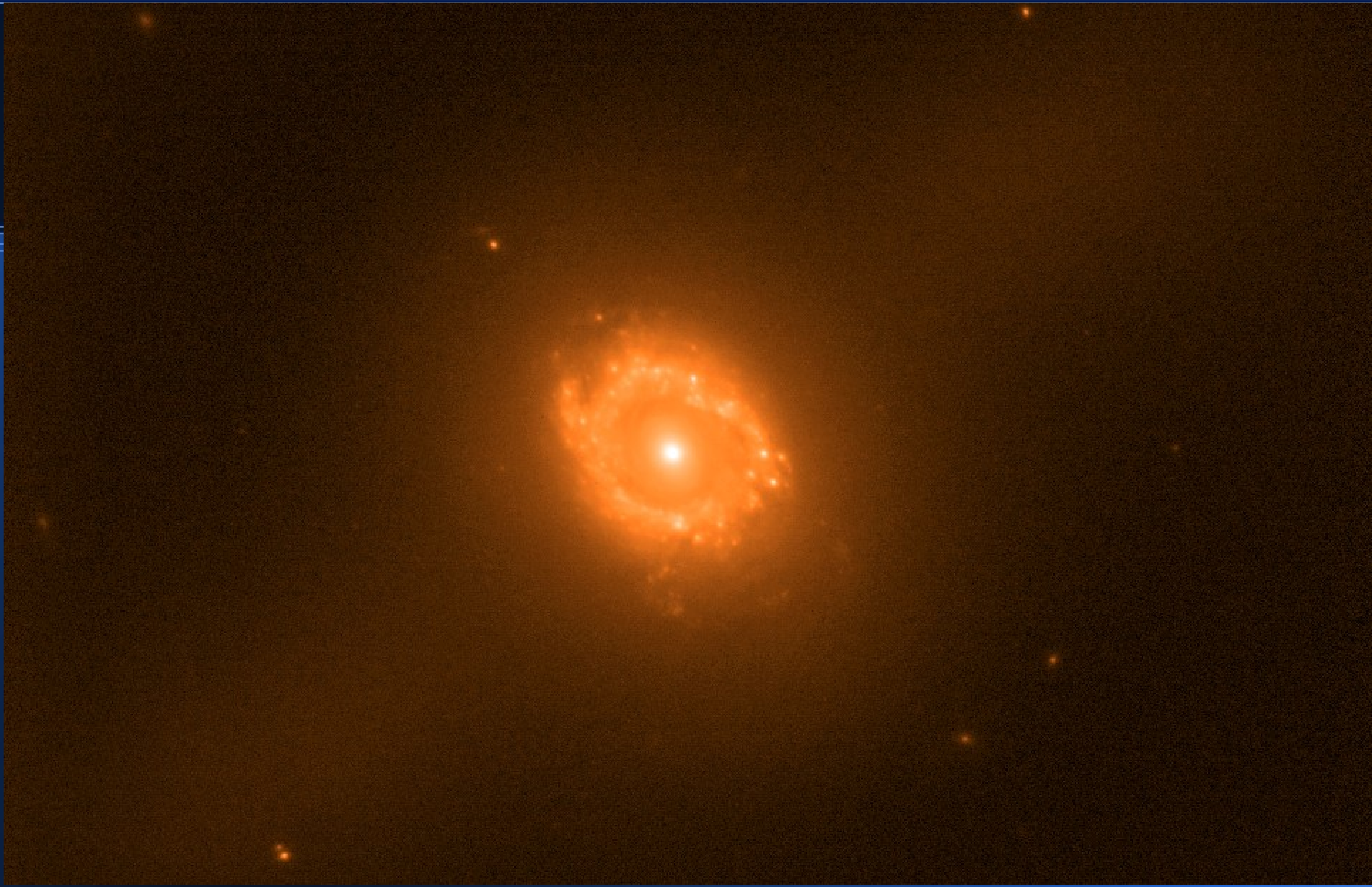
IRAS 19115-2124




IRAS 19115-2124 –
“The Bird”
You really need NIR to study (U)LIRGs
Vaisanen et al 2008a

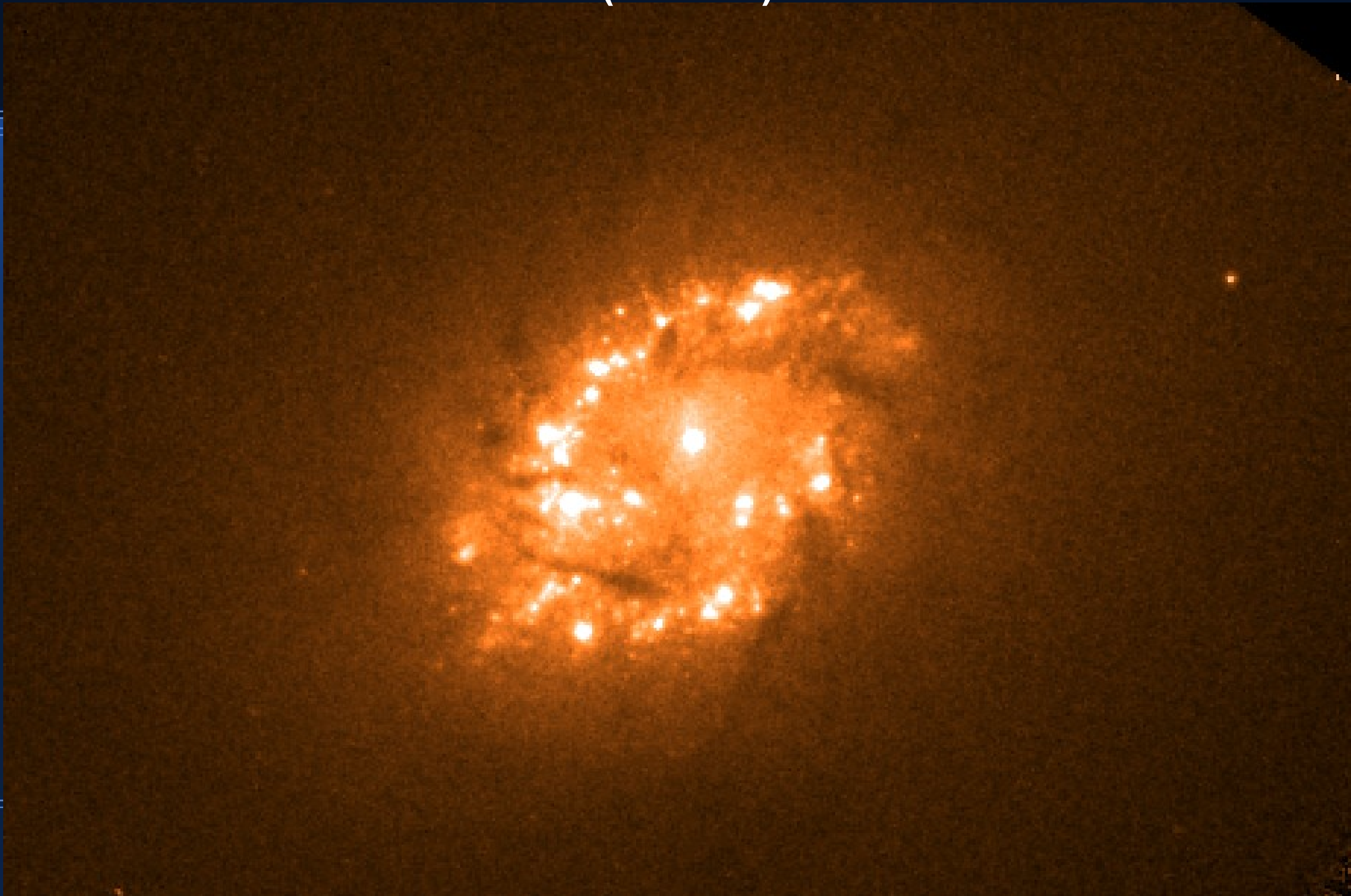


ESO 221-IG008



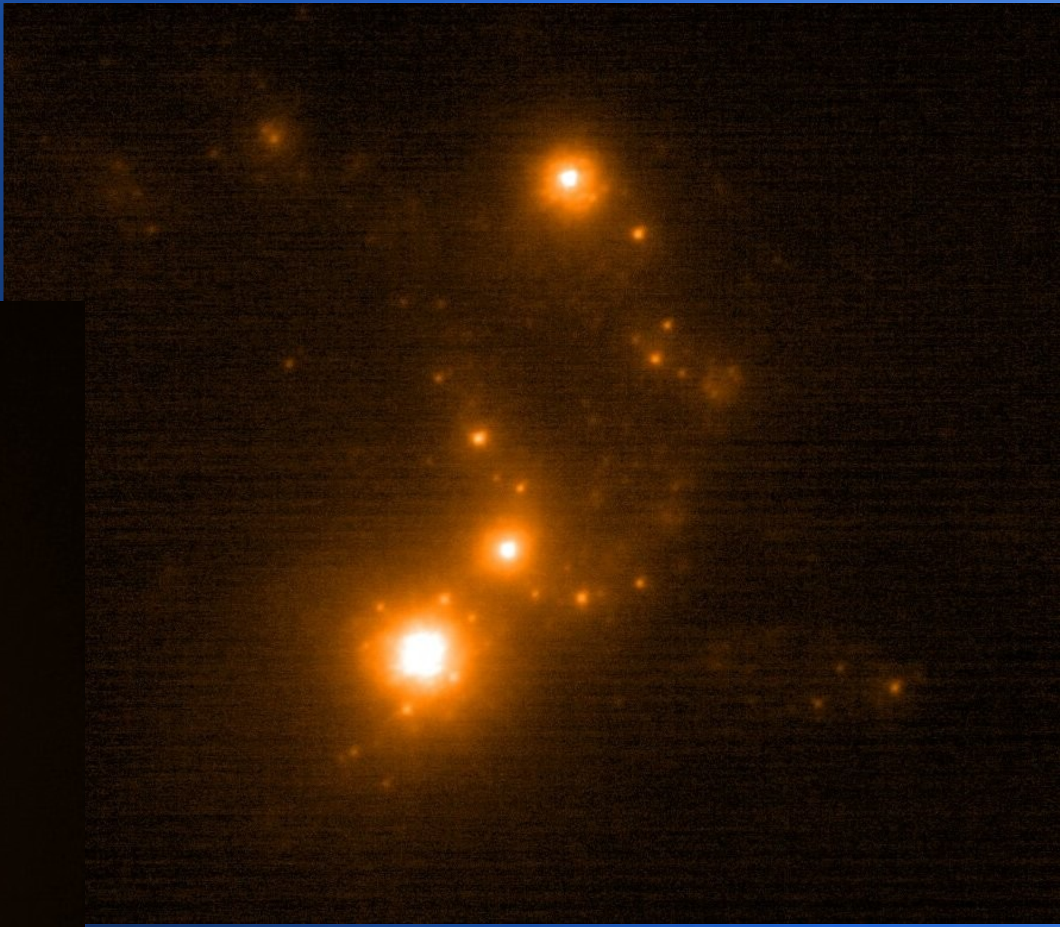
NGC 1819

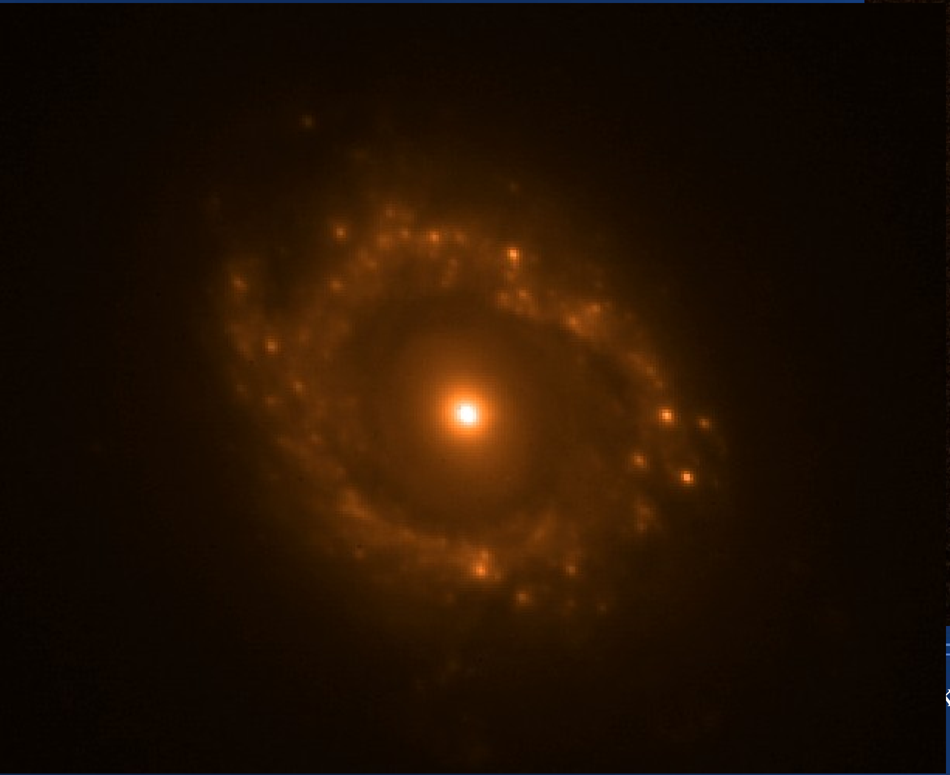
NGC 2328 (~dwarf) lenticular



Super star clusters

- Determining spatial distributions of SSCs and Luminosity Functions
- Combining HST data to model ages and masses.





ko 2012 Randriamanakoto et al. (in prep)

Super star clusters

- Most stars are born in clusters
- Most stars (in MW) are not in clusters anymore
- Very massive clusters, often called "Super Star Clusters" when >10^4 $M_\odot$
- Found especially in strongly SF galaxies

Tracers of violent SF – can study history of SF in hosts

- Interest in Young Massive Clusters:
  - Interplay of stellar evolution and stellar dynamics
  - Studies of IMF
  - Cluster IMF and evolution of clusters
  - Progenitors of Globular Clusters ?

Clusters comparison

Table 1 Comparison of fundamental parameters for star-cluster families relevant to this review: open cluster (OC), globular cluster (GC), and young massive cluster (YMC)

Cluster	Age [Gyr]	m_{to} [$M_\odot$]	M [$M_\odot$]	r_{vir} [pc]	ρ_c [$M_\odot$ pc^{-3}]	Z [$Z_\odot$]	Location	t_{dyn} [Myr]	t_{rh} [Myr]
OC	$\lesssim$0.3	$\lesssim$4	$\lesssim 10^3$	1	$\lesssim 10^3$	$\sim$1	Disk	$\sim$1	$\lesssim$100
GC	$\gtrsim$10	$\sim$0.8	$\gtrsim 10^5$	10	$\gtrsim 10^3$	$<$1	Halo	$\gtrsim$1	$\gtrsim$1000
YMC	$\lesssim$0.1	$\gtrsim$5	$\gtrsim 10^4$	1	$\gtrsim 10^3$	$\gtrsim$1	Galaxy	$\lesssim$1	$\lesssim$100

Note: The numbers in the columns are intended to be indicative of the population and are rounded off, and they should be used with care, but they provide some flavor of the various cluster types. The second column gives cluster age, followed by the turnoff mass (in solar mass), the total cluster mass (in solar mass), the virial radius r_{vir} (see Section 1.3.2), the core density, and the metallicity. The last three columns give the location in the Galaxy where these clusters are found, and the dynamical and relaxation timescales, defined in Section 1.3.3.

[Portegies Zwart et al. 2010]

Clusters comparison

Table 1 Comparison of fundamental parameters for star-cluster families relevant to this review: open cluster (OC), globular cluster (GC), and young massive cluster (YMC)

Cluster	Age [Gyr]	m_{to} [$M_\odot$]	M [$M_\odot$]	r_{vir} [pc]	ρ_c [$M_\odot$ pc^{-3}]	Z [$Z_\odot$]	Location	t_{dyn} [Myr]	t_{rh} [Myr]
OC	$\lesssim 0.3$	$\lesssim 4$	$\lesssim 10^3$	1	$\lesssim 10^3$	~ 1	Disk	~ 1	$\lesssim 100$
GC	$\gtrsim 10$	~ 0.8	$\gtrsim 10^5$	10	$\gtrsim 10^3$	<1	Halo	$\gtrsim 1$	$\gtrsim 1000$
YMC	$\lesssim 0.1$	$\gtrsim 5$	$\gtrsim 10^4$	1	$\gtrsim 10^3$	$\gtrsim 1$	Galaxy	$\lesssim 1$	$\lesssim 100$

Note: The numbers in the columns are intended to be indicative of the population and are rounded off, and they should be used with care, but they provide some flavor of the various cluster types. The second column gives cluster age, followed by the turnoff mass (in solar mass), the total cluster mass (in solar mass), the virial radius r_{vir} (see Section 1.3.2), the core density, and the metallicity. The last three columns give the location in the Galaxy where these clusters are found, and the dynamical and relaxation timescales, defined in Section 1.3.3.

[Portegies Zwart et al. 2010]

Clusters comparison

Table 1 Comparison of fundamental parameters for star-cluster families relevant to this review: open cluster (OC), globular cluster (GC), and young massive cluster (YMC)

Cluster	Age [Gyr]	m_{to} [$M_\odot$]	M [$M_\odot$]	r_{vir} [pc]	ρ_c [$M_\odot$ pc^{-3}]	Z [$Z_\odot$]	Location	t_{dyn} [Myr]	t_{rh} [Myr]
OC	$\lesssim$0.3	$\lesssim$4	$\lesssim 10^3$	1	$\lesssim 10^3$	$\sim$1	Disk	$\sim$1	$\lesssim$100
GC	$\gtrsim$10	$\sim$0.8	$\gtrsim 10^5$	10	$\gtrsim 10^3$	<1	Halo	$\gtrsim$1	$\gtrsim$1000
YMC	$\lesssim$0.1	$\gtrsim$5	$\gtrsim 10^4$	1	$\gtrsim 10^3$	$\gtrsim$1	Galaxy	$\lesssim$1	$\lesssim$100

Note: The numbers in the columns are intended to be indicative of the population and are rounded off, and they should be used with care, but they provide some flavor of the various cluster types. The second column gives cluster age, followed by the turnoff mass (in solar mass), the total cluster mass (in solar mass), the virial radius r_{vir} (see Section 1.3.2), the core density, and the metallicity. The last three columns give the location in the Galaxy where these clusters are found, and the dynamical and relaxation timescales, defined in Section 1.3.3.

[Portegies Zwart et al. 2010]

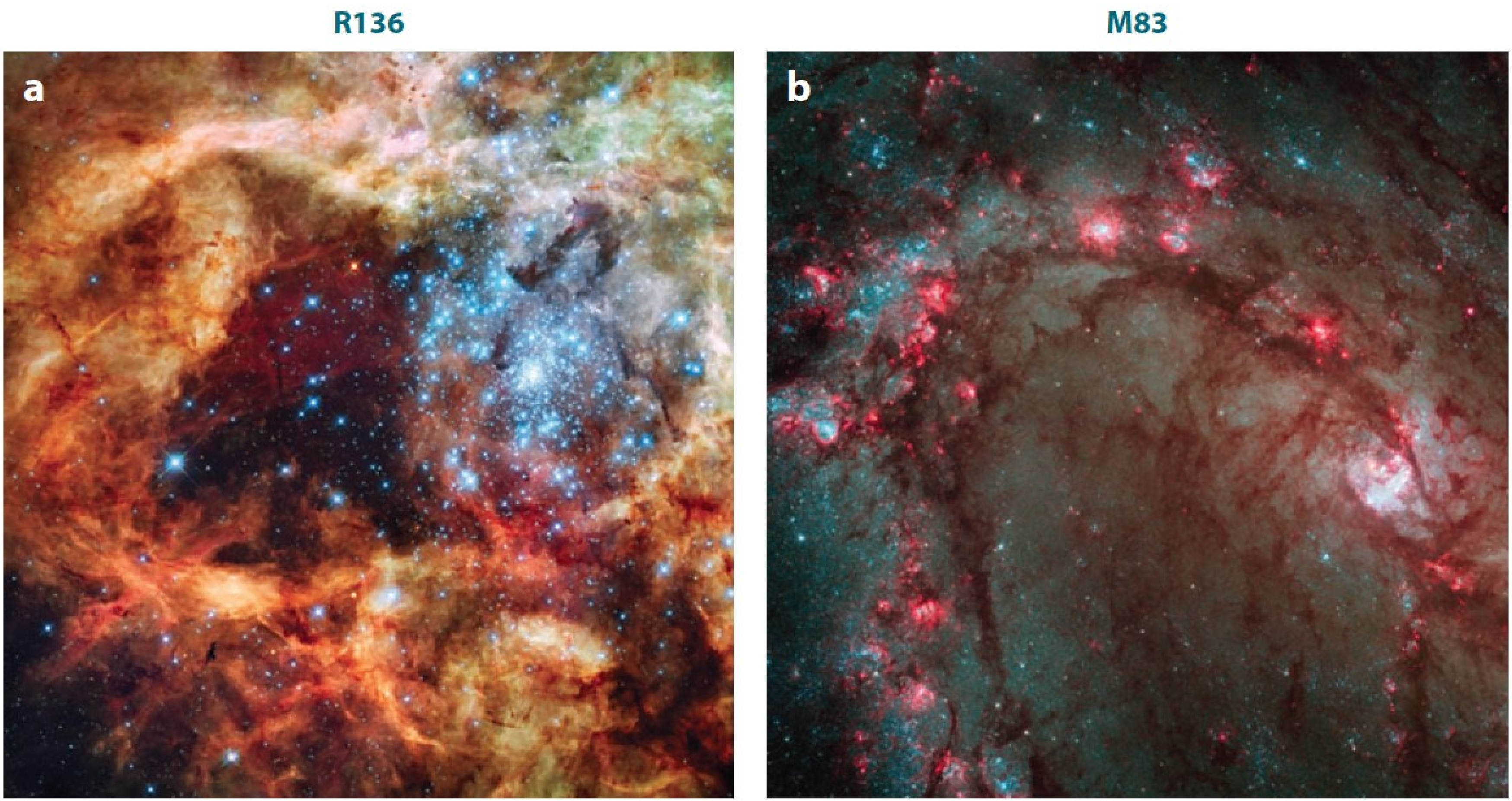


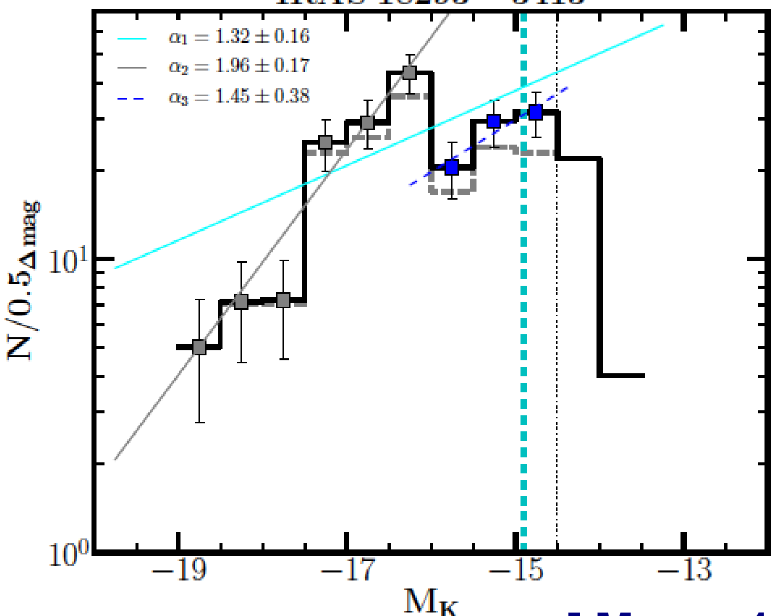
Figure 7

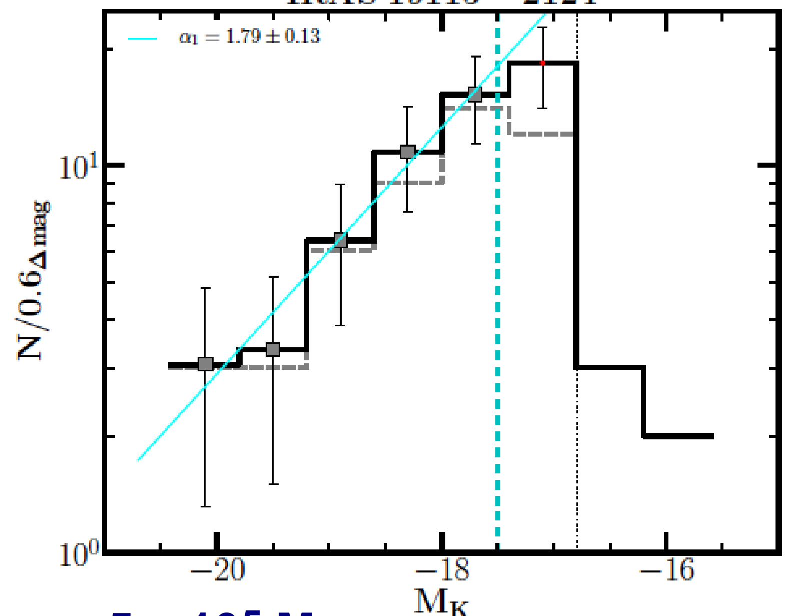
(*a*) A region of 50 × 50 pc^2 around the $\sim 10^5\, M_\odot$ cluster R136 in the 30 Doradus region of the Large Magellanic Clouds, at a distance of ~50 kpc. (*b*) Many young star clusters forming in M83 at a distance of 3.6 Mpc. Credit: NASA, ESA, the Wide Field Camera 3 Science Oversight Committee, and the Hubble Heritage Team (STScI/AURA) and F. Paresce and R. O'Connell (R136) and R. O'Connell (M83).

[Portegies Zwart et al. 2010]

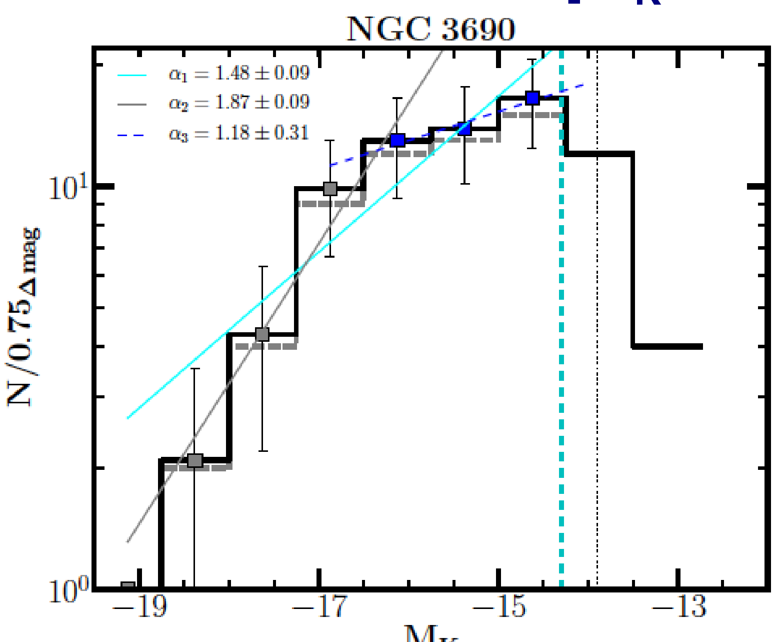
the Antennea (NGC 4038/4039)

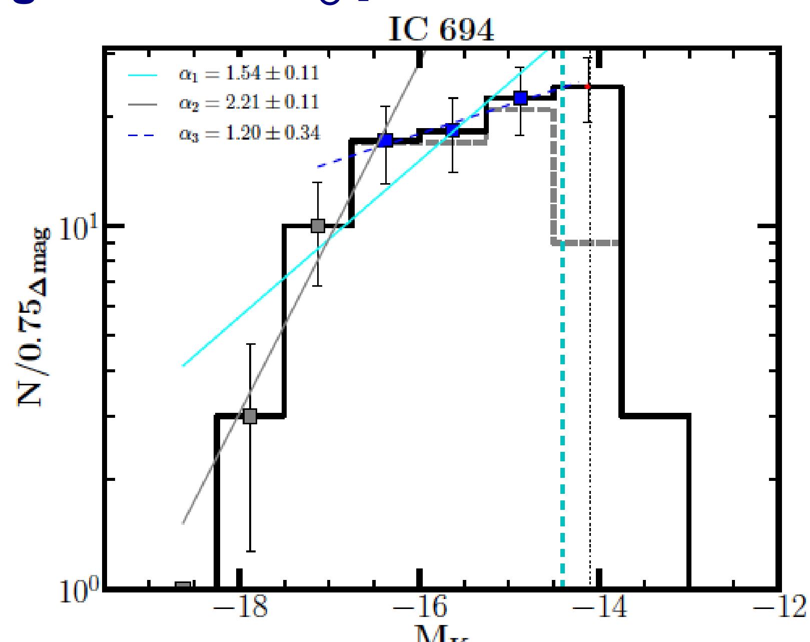
Power-law fits to LFs

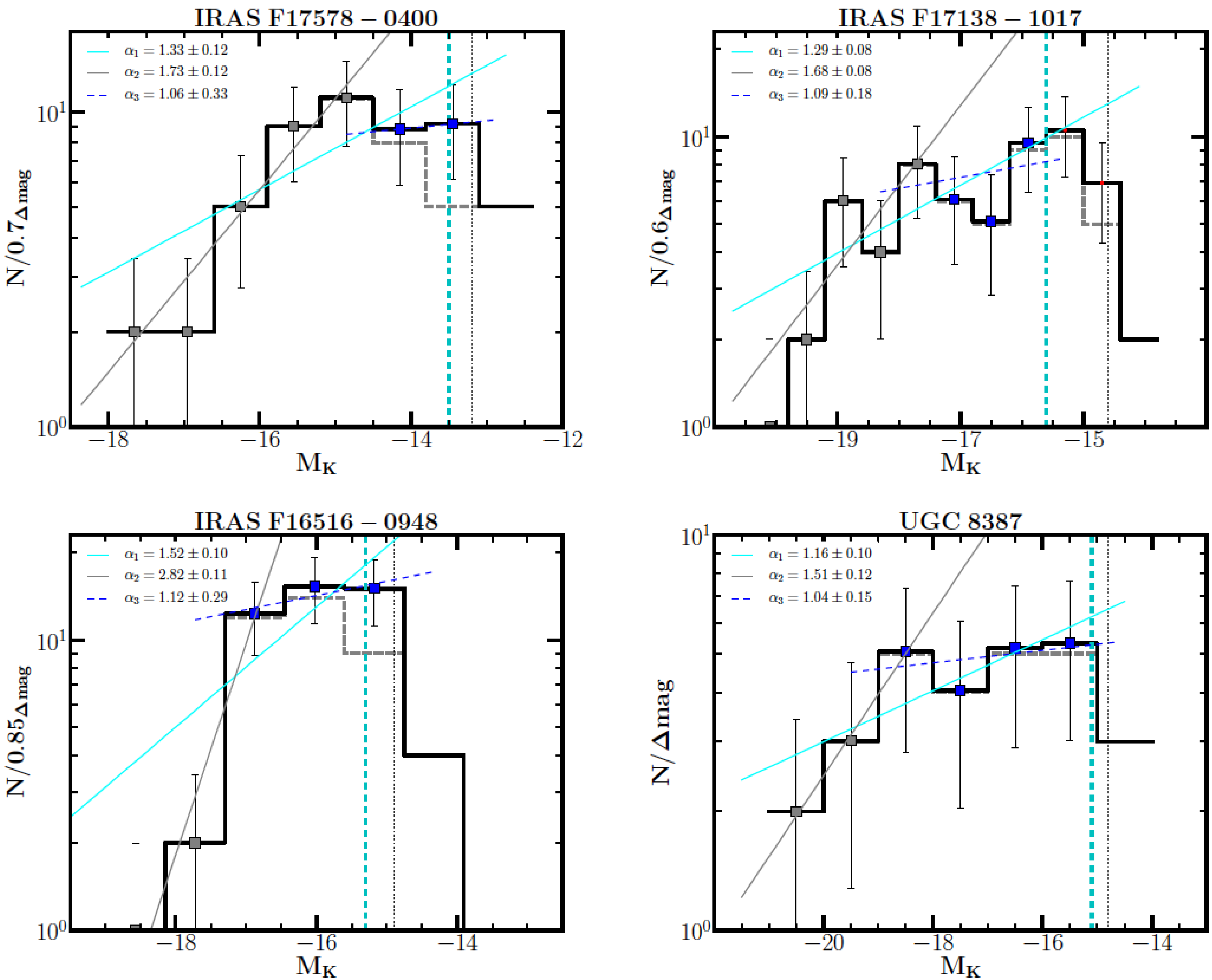




[$M_K \sim$ -16 mag ~ 5 x 10^5 $M_\odot$]







IRAS F17578 − 0400
$\alpha_1 = 1.33 \pm 0.12$
$\alpha_2 = 1.73 \pm 0.12$
$\alpha_3 = 1.06 \pm 0.33$
$N/0.7_{\Delta mag}$
M_K
IRAS F17138 − 1017
$\alpha_1 = 1.29 \pm 0.08$
$\alpha_2 = 1.68 \pm 0.08$
$\alpha_3 = 1.09 \pm 0.18$
$N/0.6_{\Delta mag}$
M_K
IRAS F16516 − 0948
$\alpha_1 = 1.52 \pm 0.10$
$\alpha_2 = 2.82 \pm 0.11$
$\alpha_3 = 1.12 \pm 0.29$
$N/0.85_{\Delta mag}$
M_K
UGC 8387
$\alpha_1 = 1.16 \pm 0.10$
$\alpha_2 = 1.51 \pm 0.12$
$\alpha_3 = 1.04 \pm 0.15$
$N/\Delta mag$
M_K

LF slopes

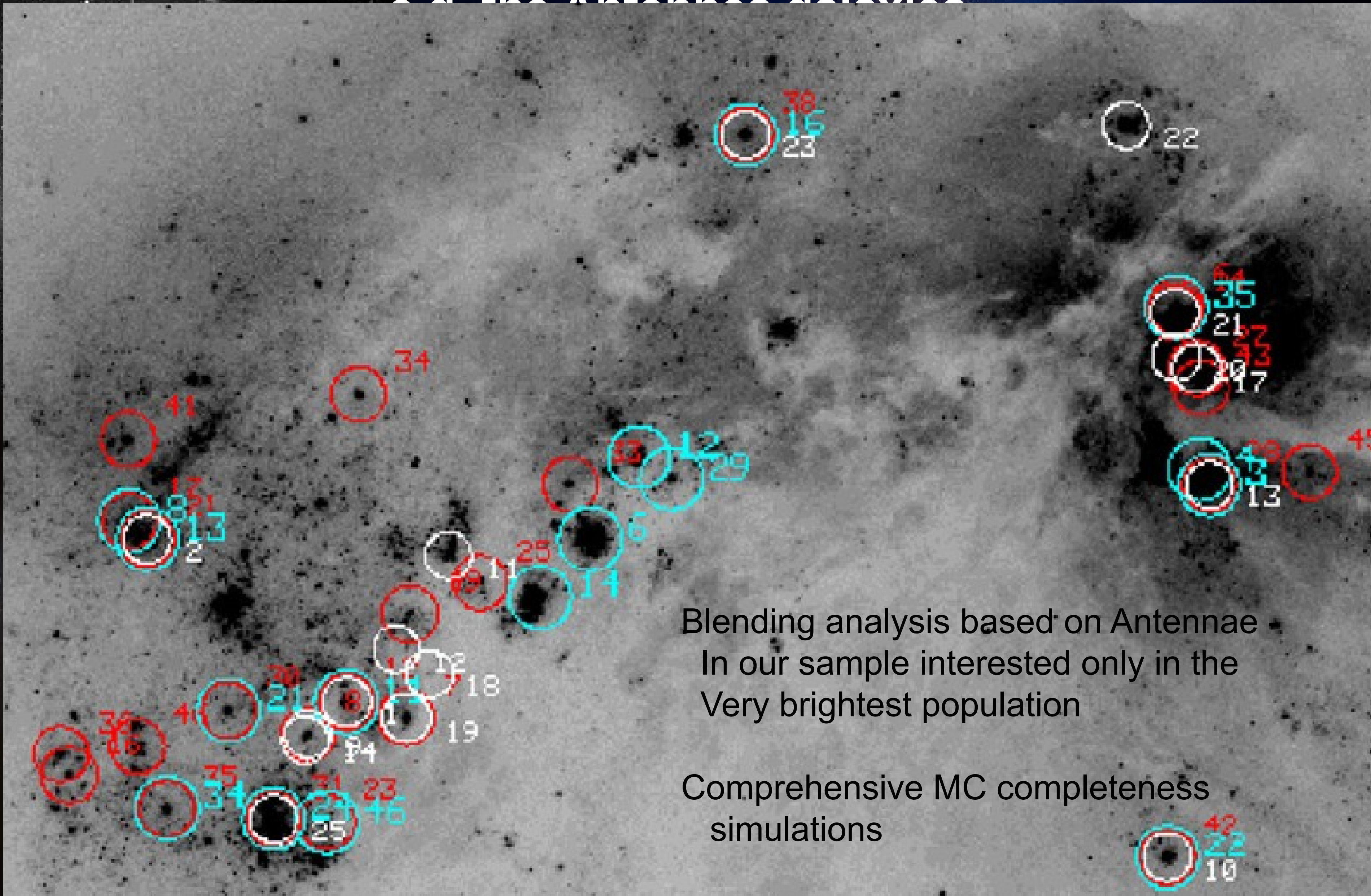
Name	α_1^{cte}	α_1^{var}	α_2	α_3	$\chi^2_{red,single}$	$\chi^2_{red,double}$	$M_K^{break/bend}$
IC 694	1.54±0.11	1.47±0.08	2.21±0.11	1.20±0.34	1.97	0.83, –	−16.375
NGC 3690	1.48±0.09	1.44±0.07	1.87±0.09	1.18±0.31	1.01	0.36, –	−16.125
UGC 8387	1.16±0.10	1.10±0.05	1.51±0.12	1.04±0.15	0.26	–,0.17	−18.500
IRAS F16516-0948	1.52±0.10	1.61±0.08	2.82±0.11	1.12±0.29	3.51	–	−16.875
IRAS F17138-1017	1.29±0.08	1.15±0.06	1.68±0.08	1.09±0.18	0.96	1.07,1.47	−17.700
IRAS F17578-0400	1.33±0.12	1.30±0.07	1.73±0.12	1.06±0.33	1.19	0.34,–	−14.500
IRAS 18293-3413	1.32±0.16	1.26±0.08	1.96±0.17	1.45±0.38	5.56	1.36, –	−16.000
IRAS 19115-2124	1.79±0.13	1.80±0.07	-	-	0.15	–,–	–
	~1.5		~2.0				

- Slopes are shallow
- Better fit with 2 components
- Bright part steeper

- Expectation based on local galaxies has been a power-law with slope $\alpha = -2$

Haikko 2012

e.g. the Antennae galaxies



Blending analysis based on Antennae
In our sample interested only in the
Very brightest population

Comprehensive MC completeness
simulations

Clusters comparison

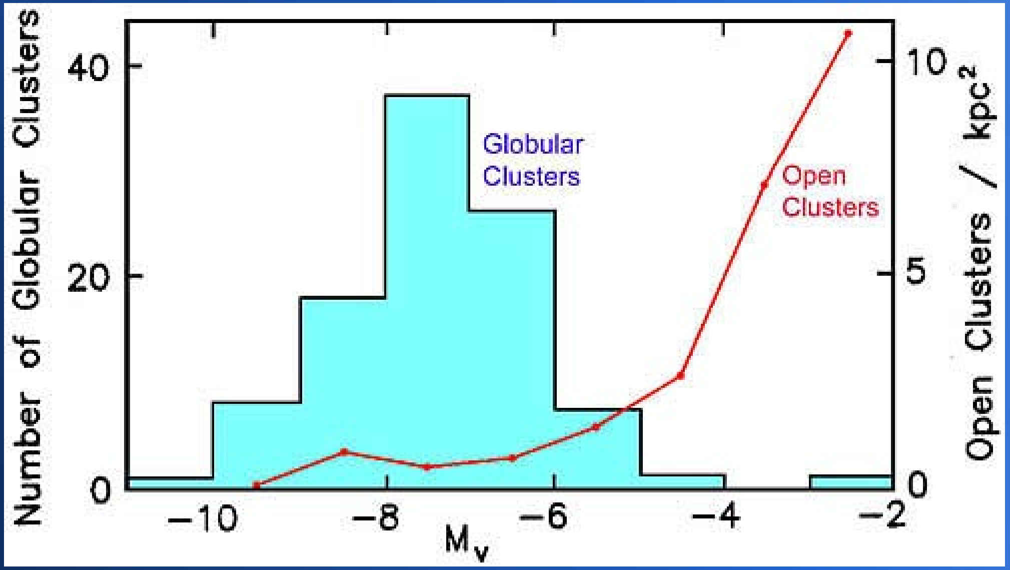
The luminosity function (LF) of GCs in the Galaxy peaks at $\mathbf{M_V} \approx -7.4$ mag,

corresponding to a typical mass of

~2 x 10^5 $M_\odot$

(Although the uncertainties are large, it appears that the majority of stars form in embedded clusters, but only a relatively small fraction (~10%) of clusters survive the embedded phase.

And then they continue to be destroyed …)



Cluster disruption

- Infant mortality
  - first few Myr
  - loss of natal gas due to winds and earliest SNe
- Mass loss due to stellar evolution
- Are these processes totally internal ?
- How important are external factors ?

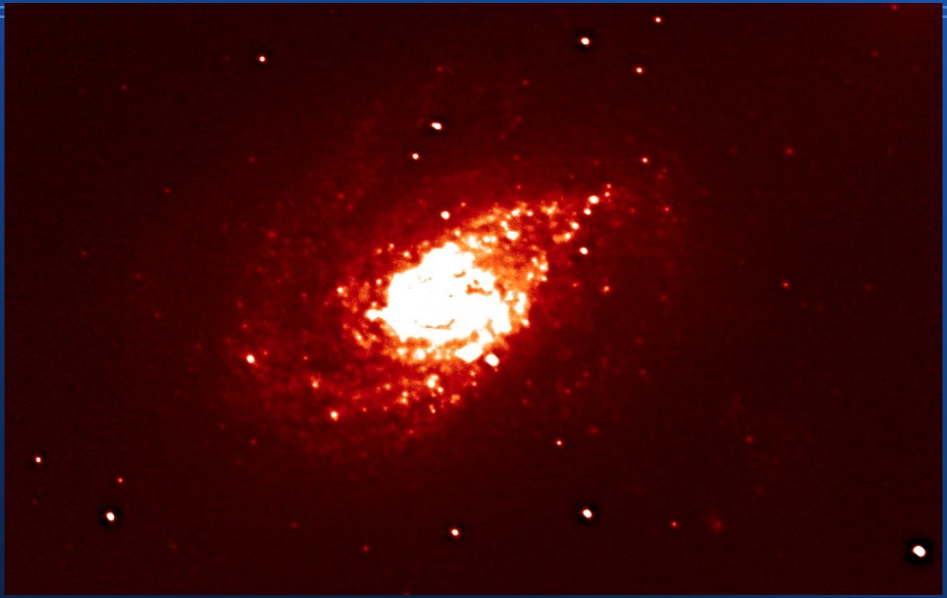
- Mass independent disruption (80-90% of SSCs are destroyed per every dex of age regardless of mass or environment) Fall et al.
- or mass dependent disruption (massive ones more likely to survive) Lamers, Bastian, et al.
- major discussions currently ...

How universal are SSC characteristics ?

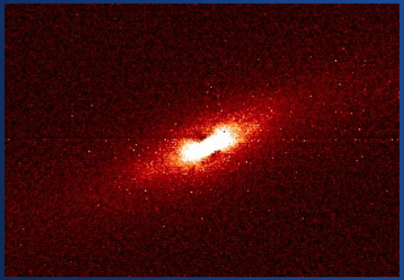
- LF universality?
- Mass-(in)dependent disruption?
- Are internal or external causes in evolution dominant?
- Can't say from our data yet
- Still to do: Age distributions, and analysis of disruption mechanisms and causes

- What we definitely see:
  - LFs have different power-law slopes
  - Breaks are different, though at similar M_K
  - Different numbers of clusters in targets

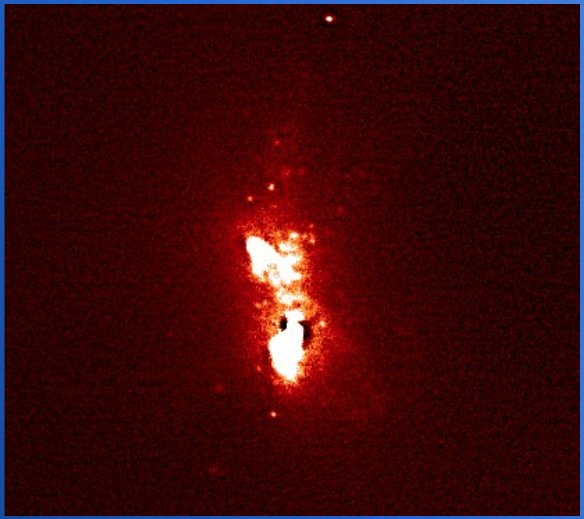
Three near-ULIRGs -
radically different numbers of SSCs



IRAS 18293-3413



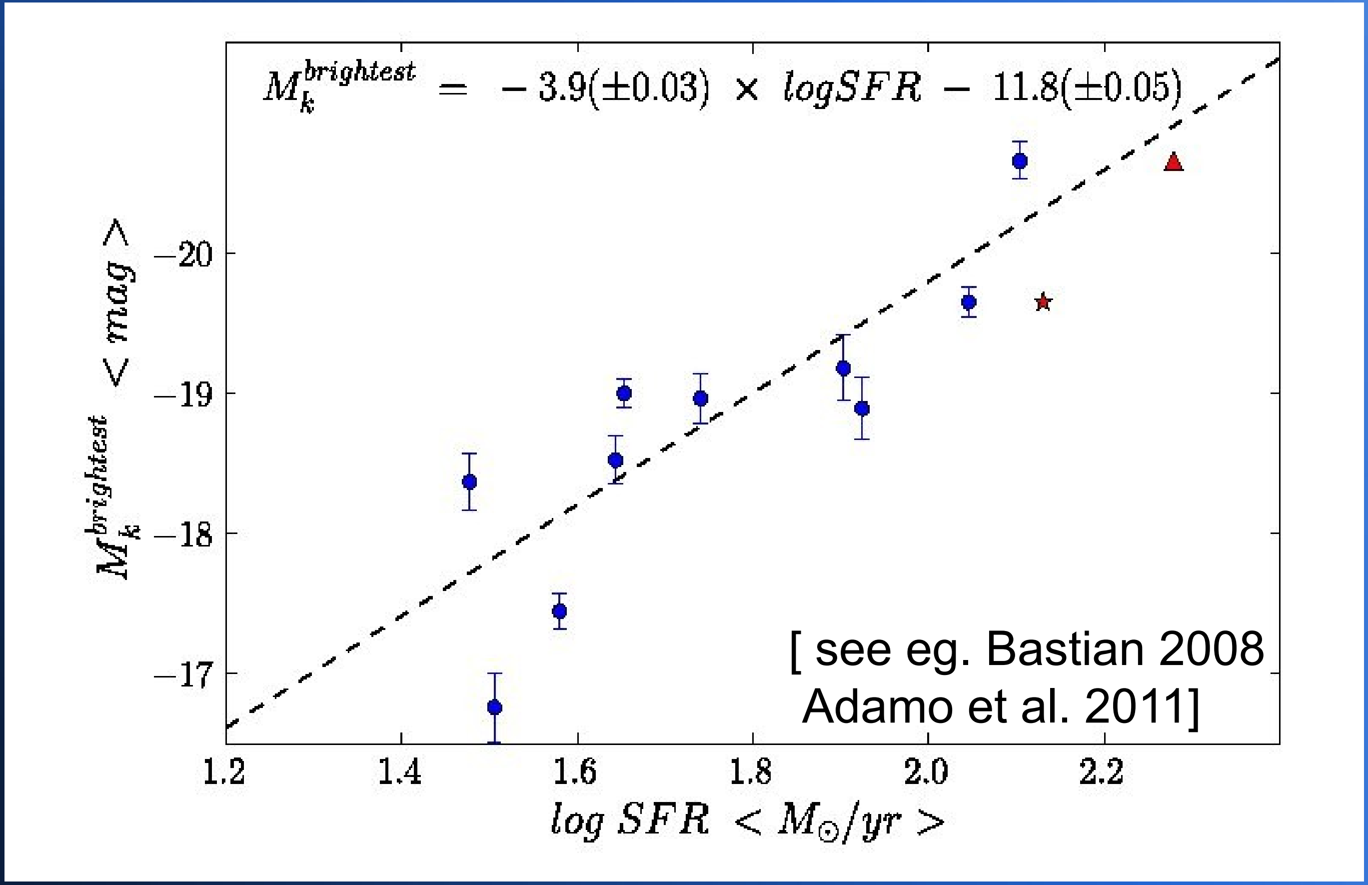
IRAS 10173+0828



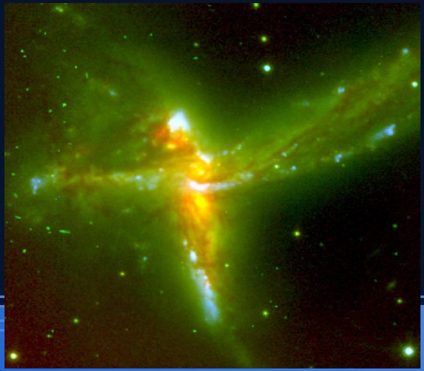
NGC 6240

Relation between SFR of host and brightest SSC

- Similar to found in optical, but different slope
- Sample size effect, or evidence of host condition dependency?



Summary



- Luminous IR-galaxies provide a sample of targets to study a variety of key phenomena especially related to triggering of star-formation and AGN activity in interactions.
- A survey of 40+ LIRGs (NACO, SALT, etc.) ongoing. NIR-AO crucial
- Super Star clusters trace violent SF – used to study hosts AND characteristics of SSC formation, evolution, disruption
- Early results: wide variety of LF shapes. Different types of hosts appear to generate different populations, but evolutionary connections yet to be determined