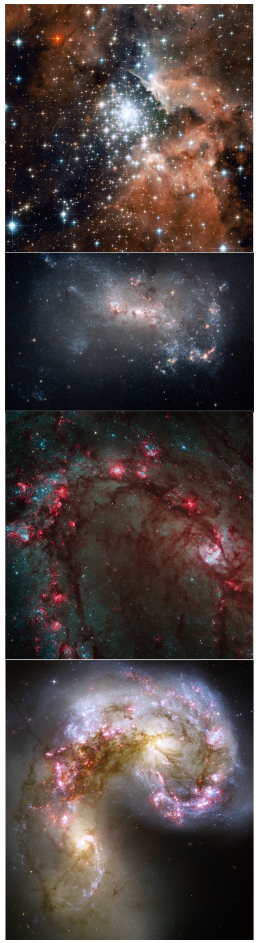


Angela Adamo,
adamo@mpia.de
Max Planck Institut fur Astronomie

THE INFLUENCE OF ENVIRONMENT ON CLUSTER FORMATION

CLUSTER FORMATION AND ENVIRONMENT

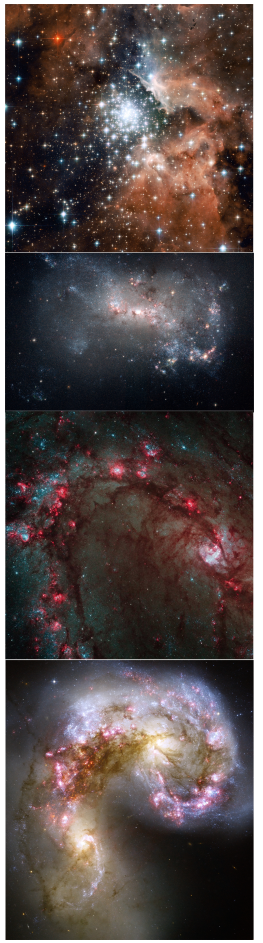
extragalactic

- Some general statements (from the observer PoV)

- A look outside our Galaxy:

  Cluster and star formation in the local Universe (< 100 Mpc)

  Dwarf systems – Spirals – Starbursts (mergers)

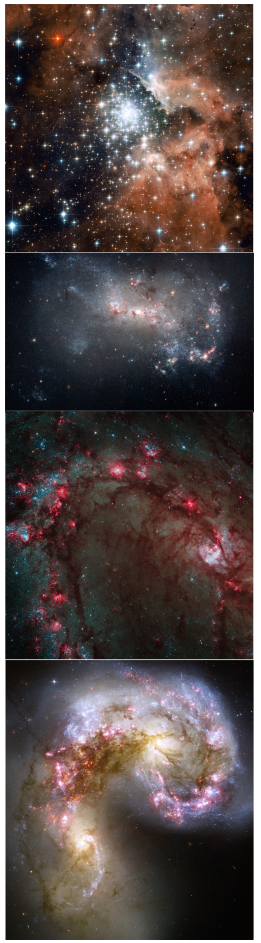


- Scaling relations: Cluster formation versus SFR

OUTLINE

STAR FORMATION (SF) IN GIANT MOLECULAR CLOUDS (GMC)

- Star formation is hierarchical in space and time
- turbulence → transient and inhomogeneous molecular clouds → localized compressed pocket of gas
- High-density regions, exceeding the critical mass for gravitational contraction, collapse (Jeans unstable clumps/cores)

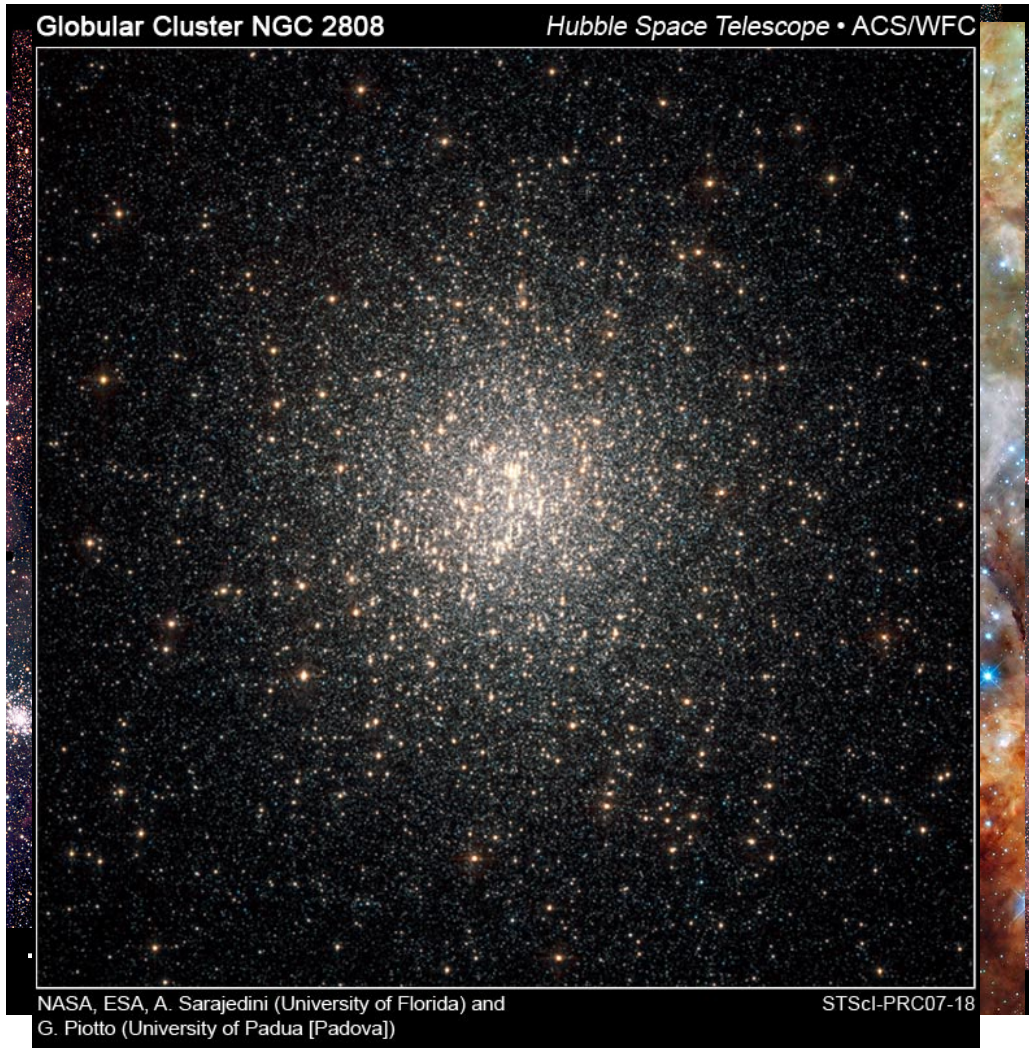


SF FROM GMC TO CLUMP SCALES

Elmegreen (2011), Klessen (2011)

WHAT IS A STAR CLUSTER?

- A look at the local Universe:



Gravitationally bound

Surrounded by dust
and ionized gas
(first ~10 Myr)

Massive, $10^{3\text{-}6}$ Msun

Formed in a single burst

Compact, radius ~ 1-5 pc

Survive up to Hubble time!

WHY DO WE STUDY STAR CLUSTERS?

- commonly produced in star formation events
  → Tracers of the host star formation history

- Easy to model
  → Formed by a single stellar population

- Easy to detect (< 100 Mpc)
  → Brighter then single stars

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OPEN ISSUES

- What fraction of stars does form in clusters?
- Does this depend on environment?
- Which fraction does survive?

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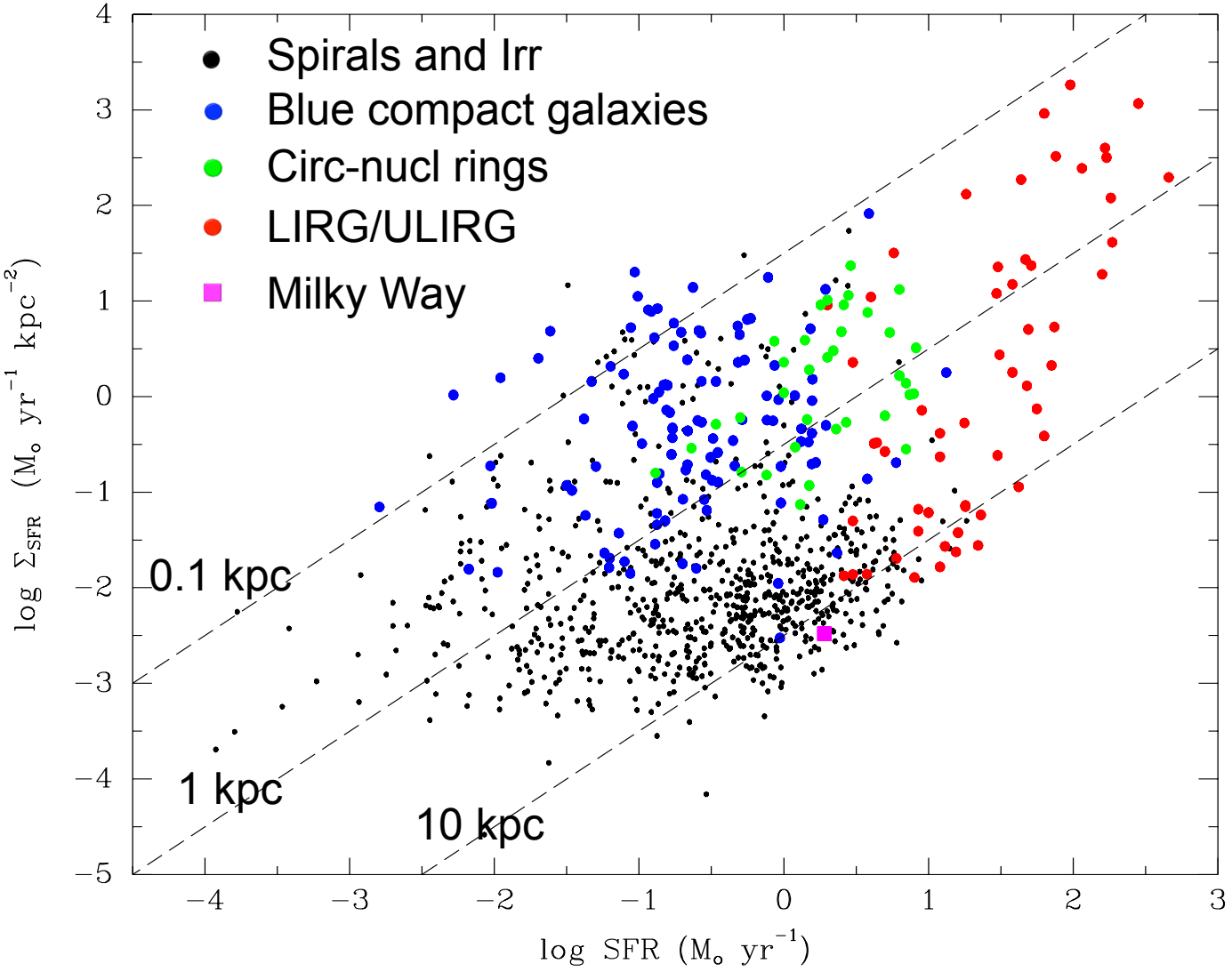
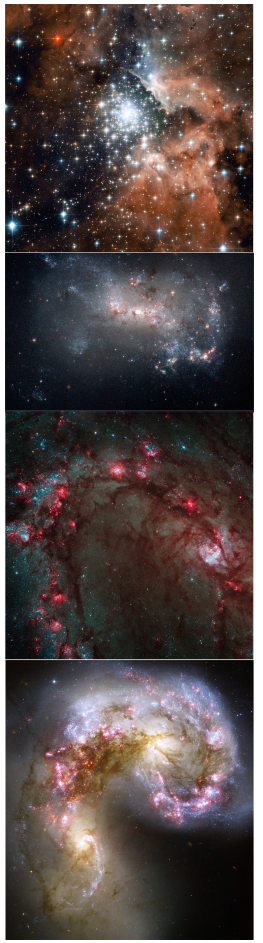


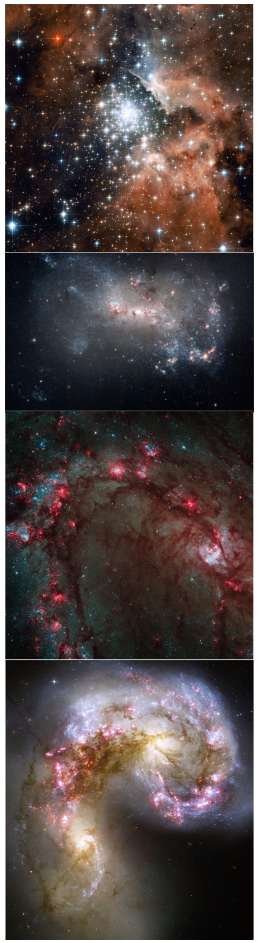


STAR FORMATION RATE (SFR) AS FUNCTION OF THE ENVIRONMENT

Review by
Kennicutt & Evans (2012)

LOW SF AND GAS DENSITY REGIMES

- M_B > -18 mag (Dwarfs and Irregulars)
- 60 local Dws and Irrs:
  - ~50% (32) Do not have clusters
  - ~10% (7) Have only clusters >100 Myr
  - ~40% (21) have YSCs < 100 Myr



CLUSTER FORMATION IN DWARF GALAXIES

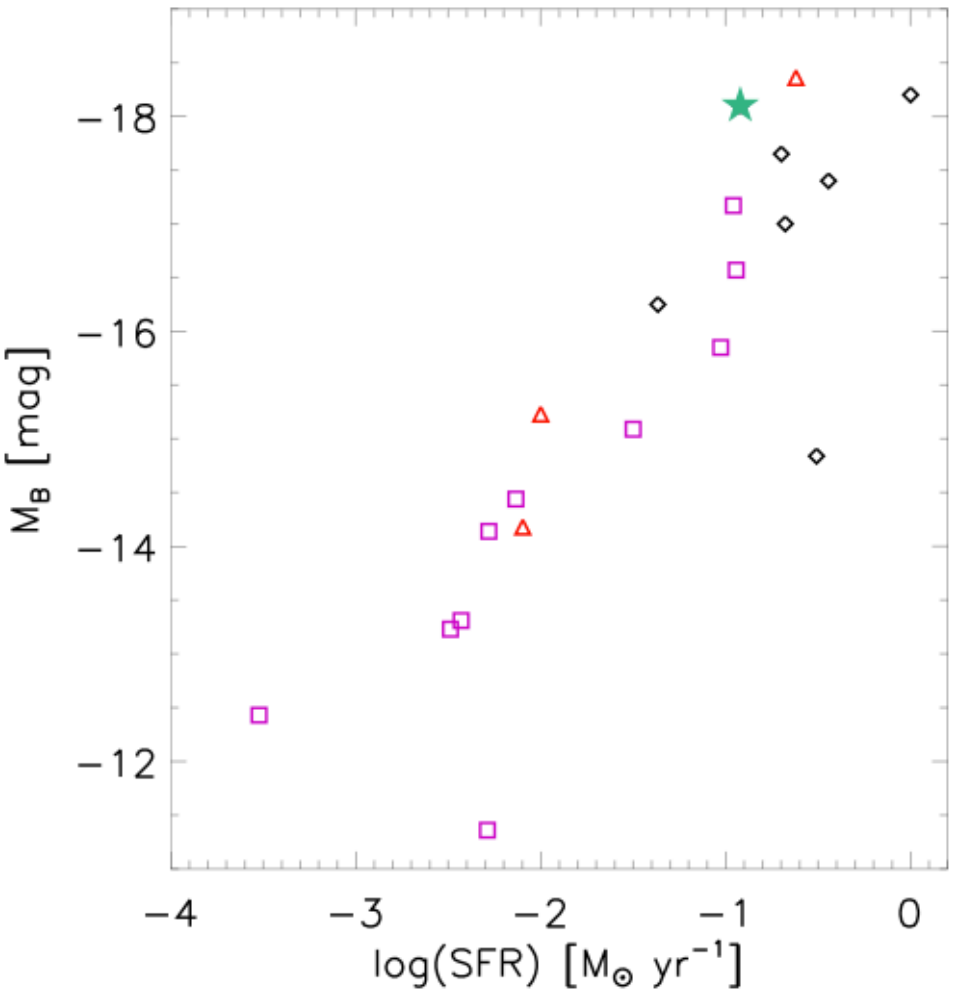
Billett et al (2002), Cook et al (2012), 5 dwarf starburst from literature

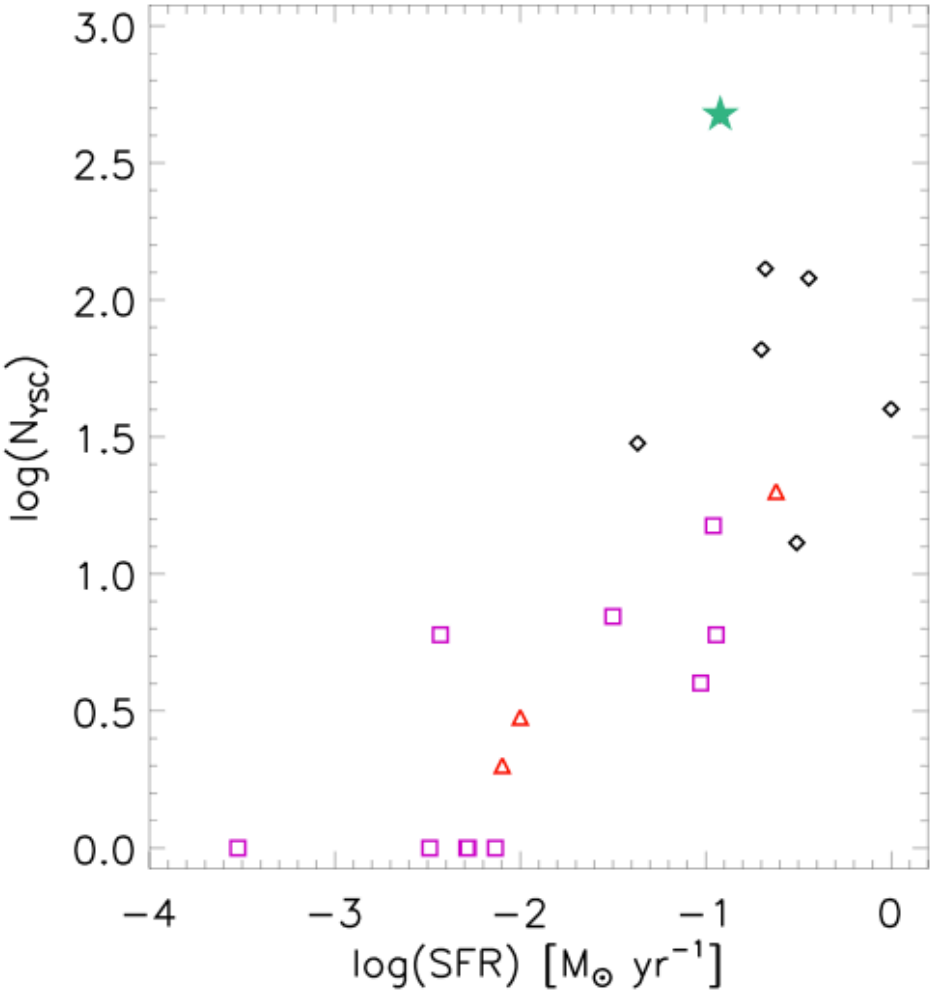
LMC

NGC4449, NGC1569, He2-10, SMC, NGC1705, NGC5253

Cook et al 12

Billett et al 02



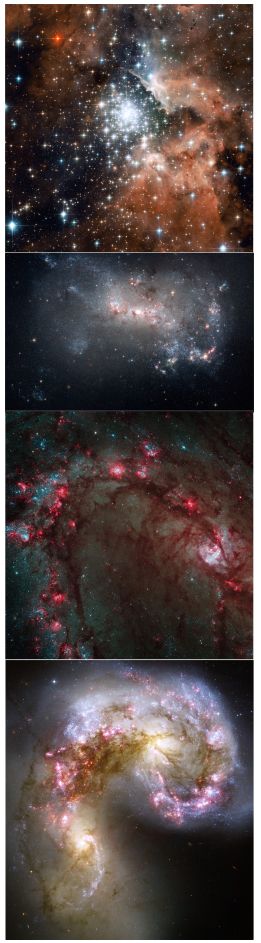


CLUSTER FORMATION IN DWARF GALAXIES

CLUSTER FORMATION IN DWARF GALAXIES

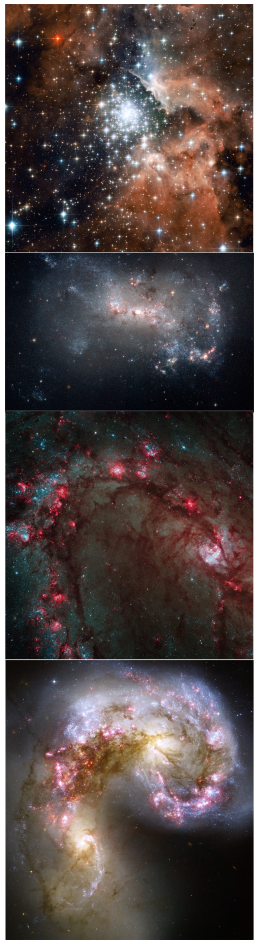
- In Dws and Irrs star formation happens in compact regions
- Burst events are episodic and localised
- The formation of clusters is a “complicated” process:

1) A central massive cluster is formed→ stellar feedback quenches SF, lower mass clusters are formed after a few Myr (NGC1569, NGC1705, etc);
2) More clusters are produced during the same burst event (NGC4449, IC 2574)
3) At very low SF regime the galaxy is able to form a few (maybe one) clusters (Cook sample)



Billett et al (2002)
Cook et al (2012)

- The sporadic formation of (massive) clusters could be correlated to the environment:
  1) End of bar flows or shell collisions (30 Dor)
  2) The lack of shear
  3) Gravitational instability (GMCs size comparable to the local Jeans scale)
  4) In nuclear regions, ambient density and pressure are high (very massive central clusters)



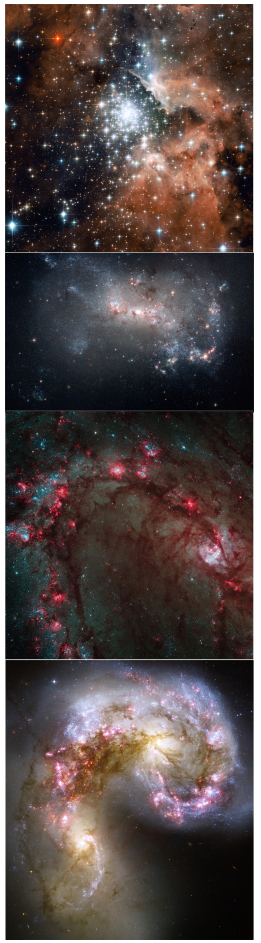
CLUSTER FORMATION IN DWARF GALAXIES

Billett et al (2002)
Cook et al (2012)

CLUSTER FORMATION IN SPIRALS

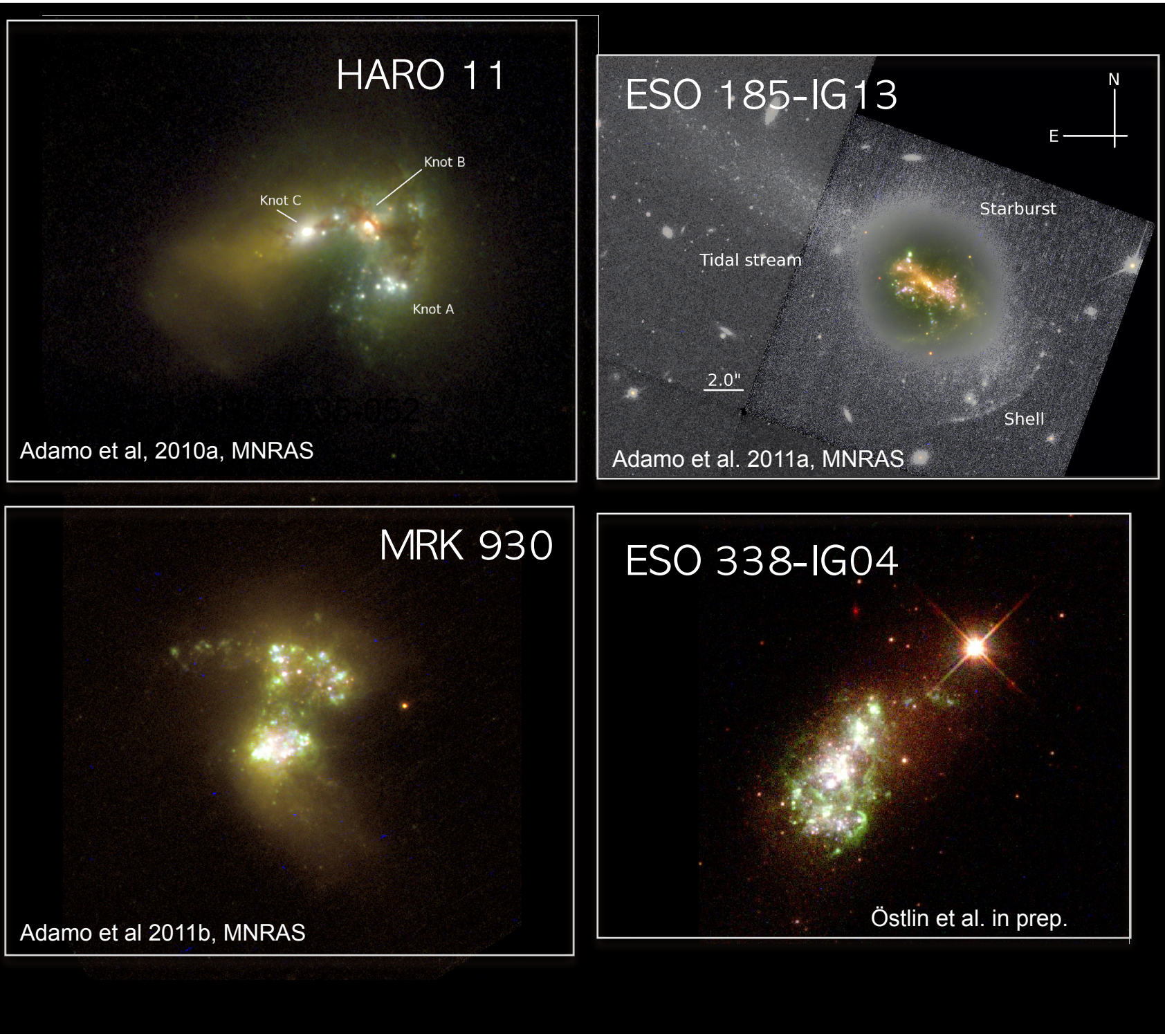
- Dynamically spiral galaxies are more active:
  1) spiral wavemode as response to gravitational instability
  2) arms (interarms) have usually low (high) shear and tidal forces
  3) streaming motions

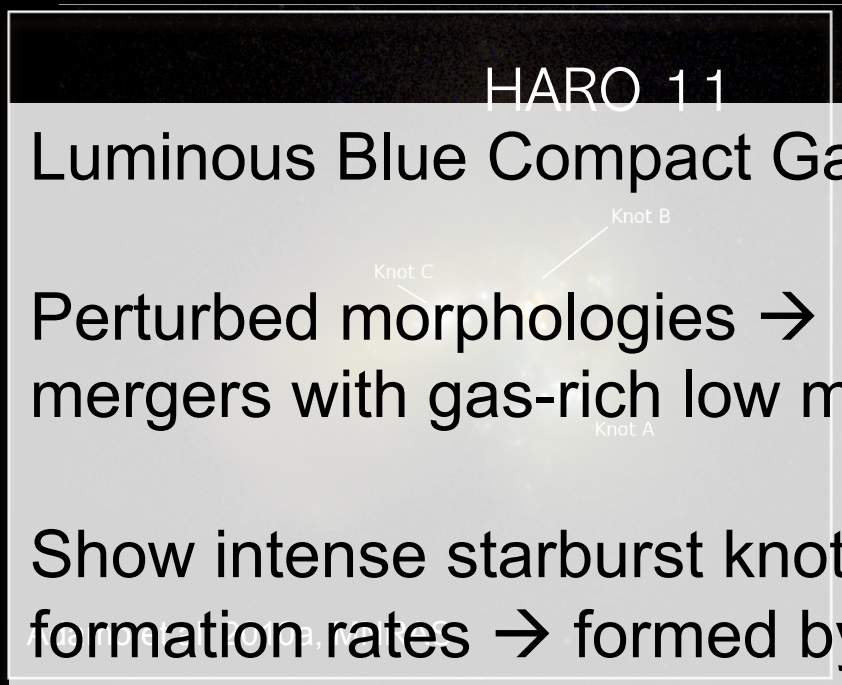
→ *As consequence SFR per unit area is higher in the arms. However, the spiral arms do not increase the global SFR per unit molecular gas*

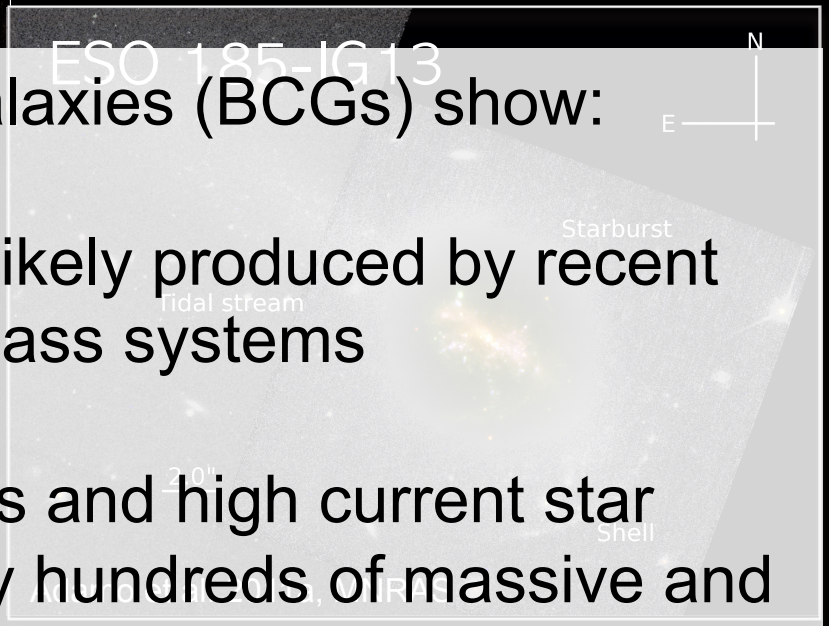


Clusters form at a quite constant rate (N_{YSC} > a few 100s)

Elmegreen (2011)
Sharon's talk


HARO 11
Knot B
Knot C
Knot A
Adamo et al, 2010a, MNRAS
ESO 185-IG13
N
E
Starburst
Tidal stream
2.0"
Shell
Adamo et al. 2011a, MNRAS
MRK 930
Adamo et al 2011b, MNRAS
ESO 338-IG04
Östlin et al. in prep.

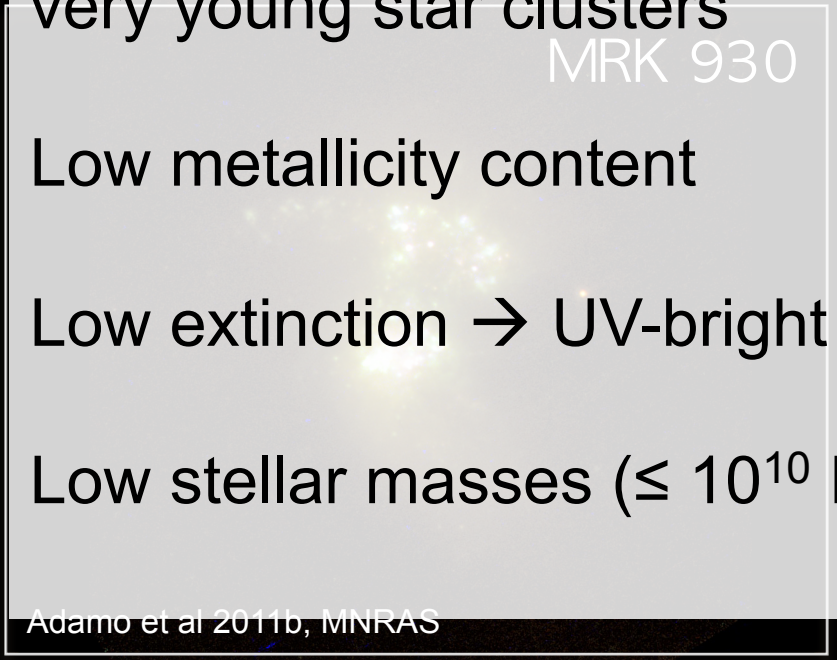




Luminous Blue Compact Galaxies (BCGs) show:

Perturbed morphologies → likely produced by recent mergers with gas-rich low mass systems

Show intense starburst knots and high current star formation rates → formed by hundreds of massive and very young star clusters



Low metallicity content

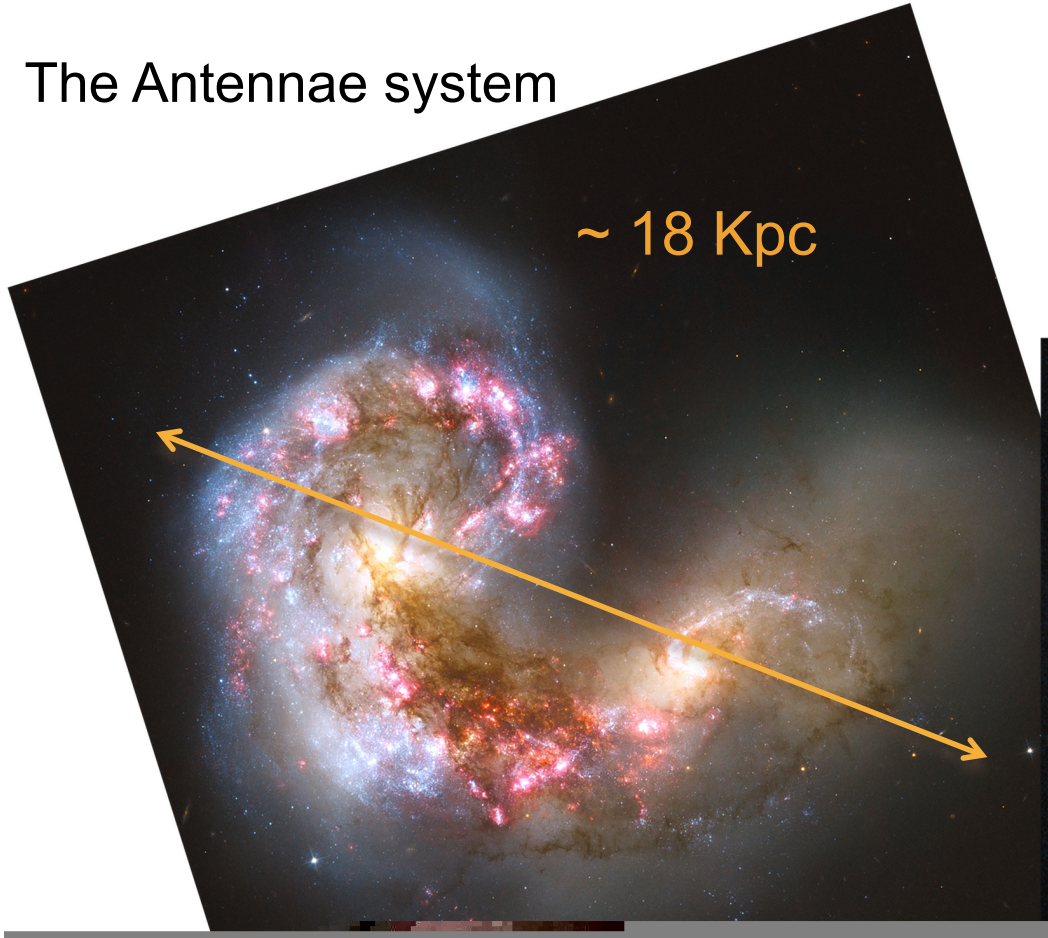
Low extinction → UV-bright systems

Low stellar masses ($\leq 10^{10}$ $M_{\odot}$)

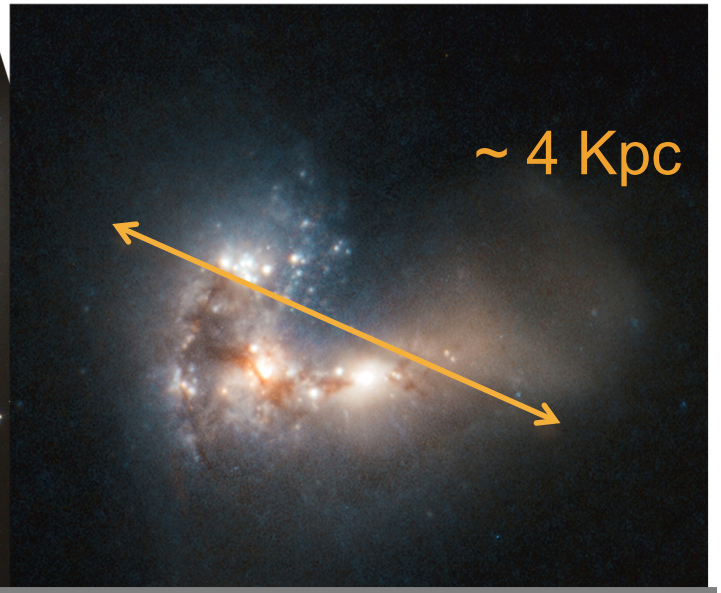
Adamo et al 2011b, MNRAS

Östlin et al. in prep.

The Antennae system



Haro 11



@Hubble Heritage team

Adamo PhD thesis

CLUSTER FORMATION IN MERGERS

Adamo et al 2010

CLUSTER FORMATION IN MERGERS

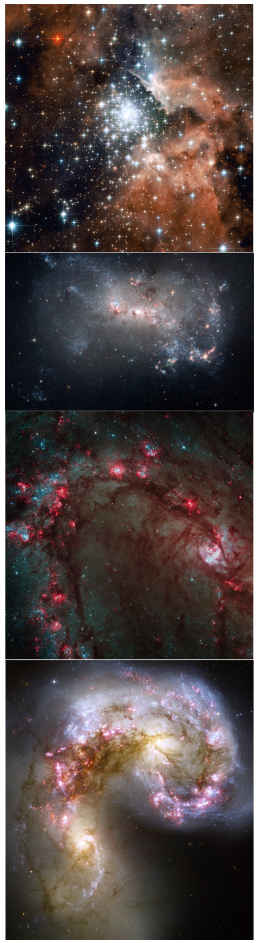
- Merger systems:

  1) gas experience high compression and elevated external pressures

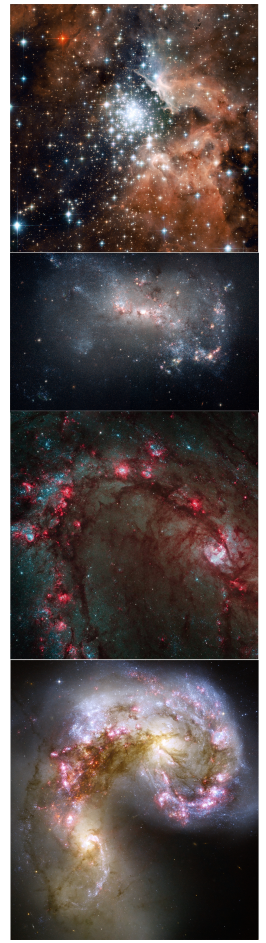
  2) gravitational instabilities are not local but global

  3) SFR increases → higher cluster formation efficiency

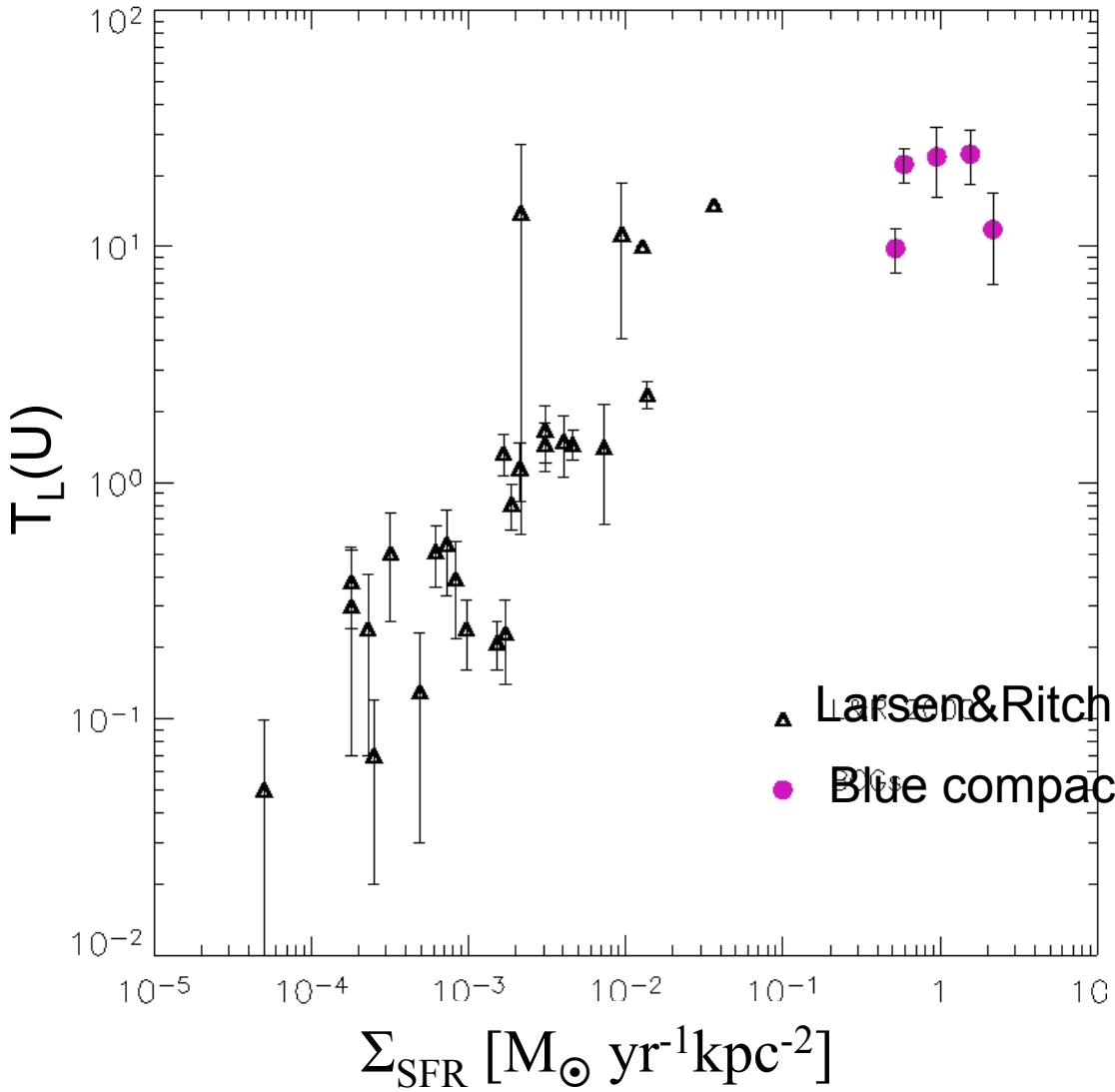
  4) very massive clusters are formed → most massive YSC are found in mergers, M>= 1x10^7 Msun (W3 and W30, Bastian et al 2006; WS80, Whitmore & Zang 2002)



How can we relate star formation to cluster formation?



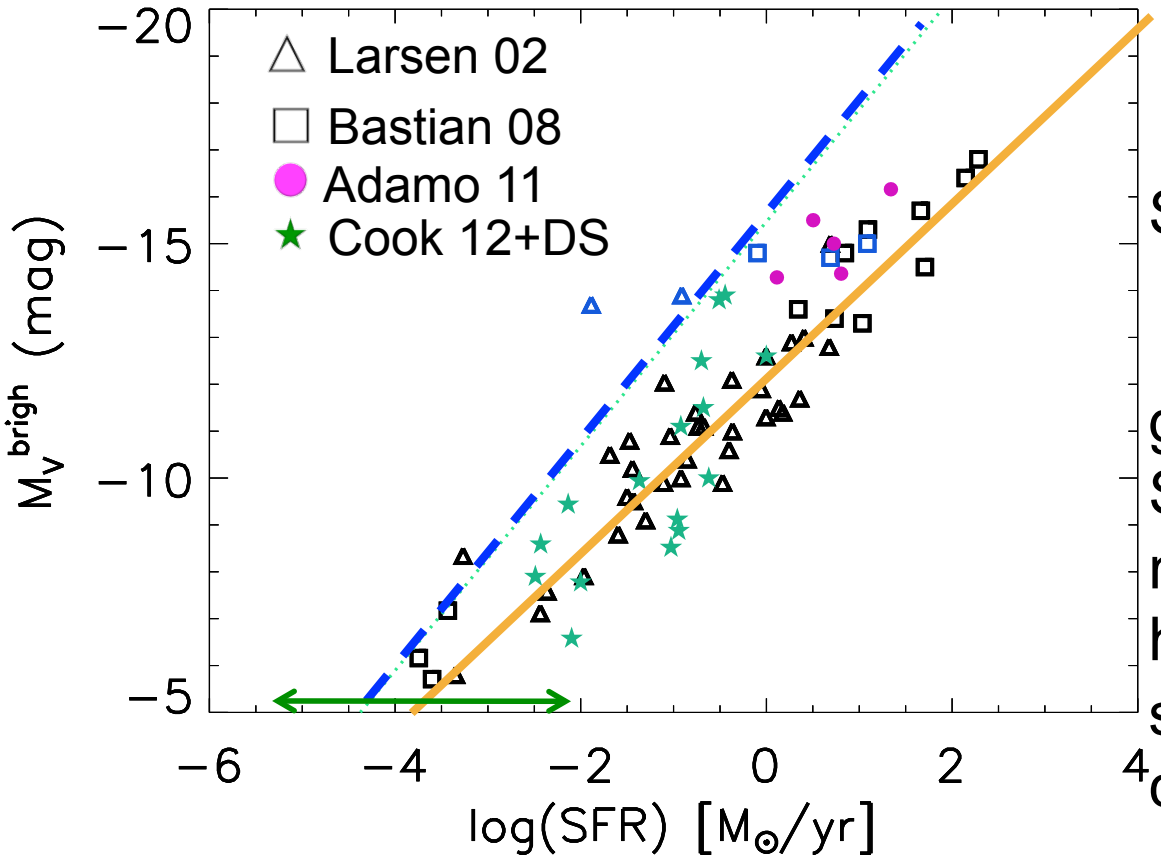
Scaling relations



$T_L(U) = L_{cluster}/L_{host}$ [%]

FRACTION OF STARS FORMING IN CLUSTERS

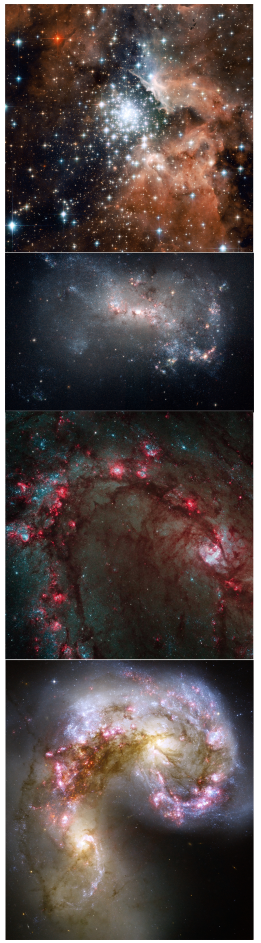
Larsen & Ritchler (2000)
Adamo et al (2011)



~8 % of stars form in clusters

Size of sample effect

galaxies with higher SFR can form more massive clusters → higher probability to sample the high mass cluster bins



Mv (brightest) → is a young cluster and not the most massive

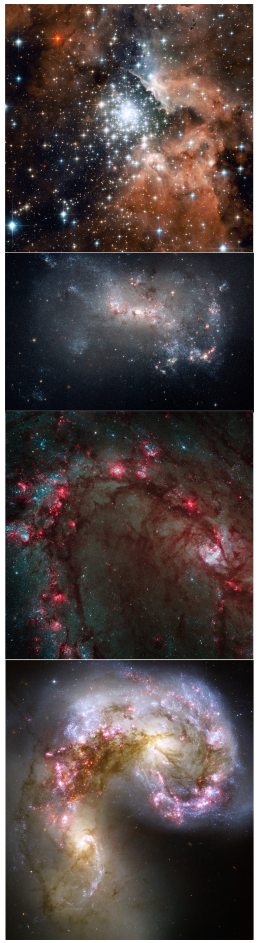
THE MOST LUMINOUS YSC IN NEARBY GALAXIES

Larsen (2002, 2009), Bastian (2008), Adamo et al (2011), Cook et al. (2012)

CLUSTER FORMATION EFFICIENCY

- Cluster formation efficiency → the fraction of star formation which happens in bound clusters

$$\Gamma(\%) = \frac{\text{Cluster formation rate}}{\text{Star formation rate}}$$ Bastian (2008)



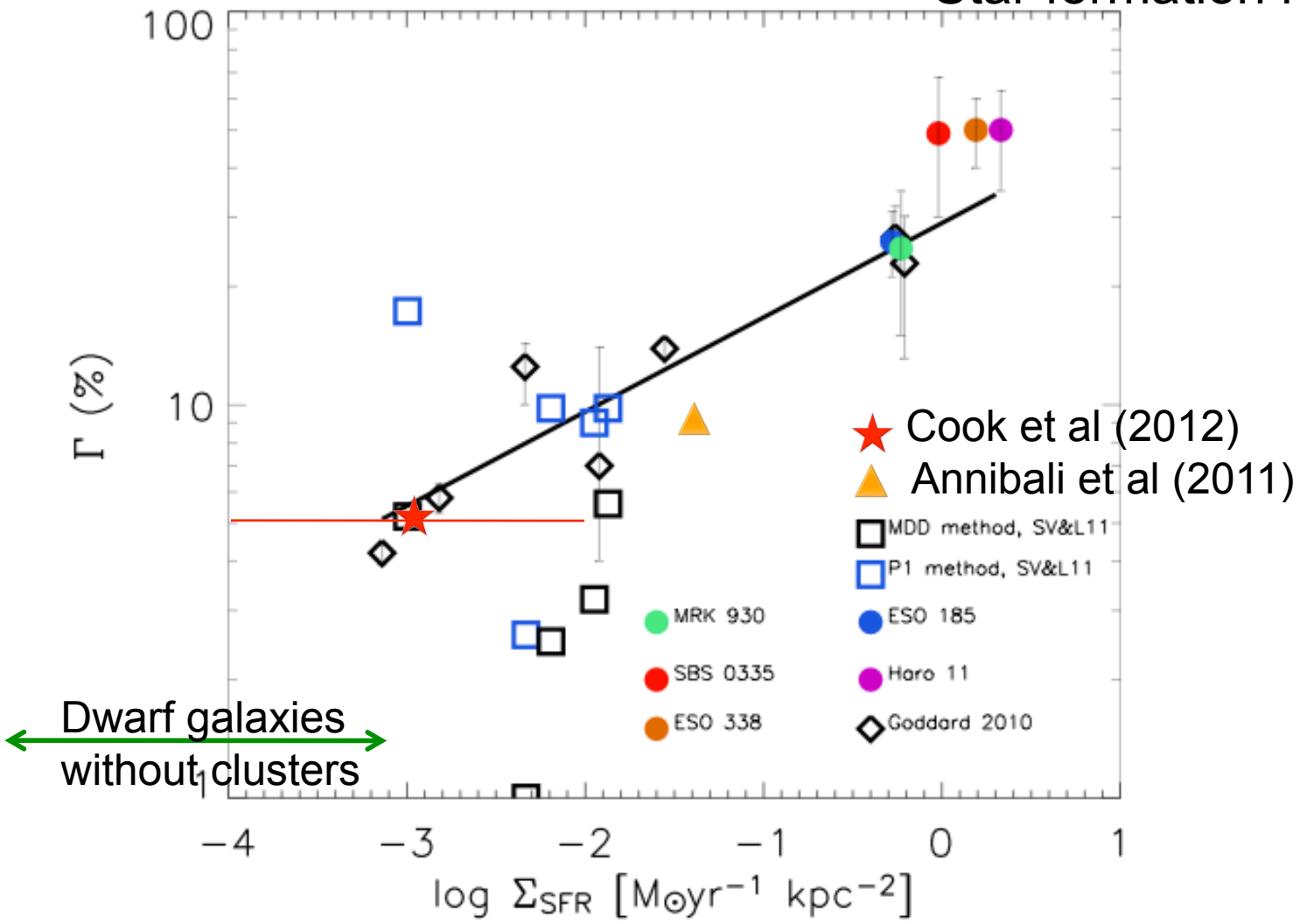
Methods to derive CFR:

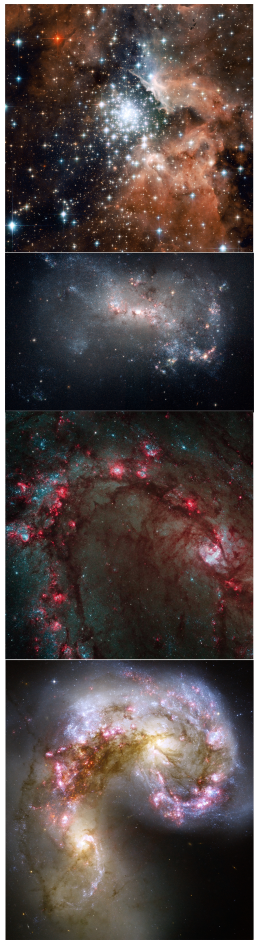
1) Assume a CMF, and the total stellar mass formed in clusters in the last 10 Myr → current SFR (Hα , L_{ir}, CMD of the stellar field population)

[Goddard et al (2010), Adamo et al (2011); Annibali et al (2011);Cook et al (2012)]

2) Assume a CMF, a cluster disruption model; perform a fit to the observed cluster luminosity function → constant SFR [Silva-Villa & Larsen (2011)]

$$\Gamma(\%) = \frac{\text{Cluster formation rate}}{\text{Star formation rate}}$$





Dwarf galaxies without clusters

CLUSTER FORMATION EFFICIENCY

D. Kruijssen's talk for an analytic fit to the data

Goddard et al 2010, Adamo et al 2011, Silva-Villa&Larsen (2011)

CLUSTER FORMATION EFFICIENCY

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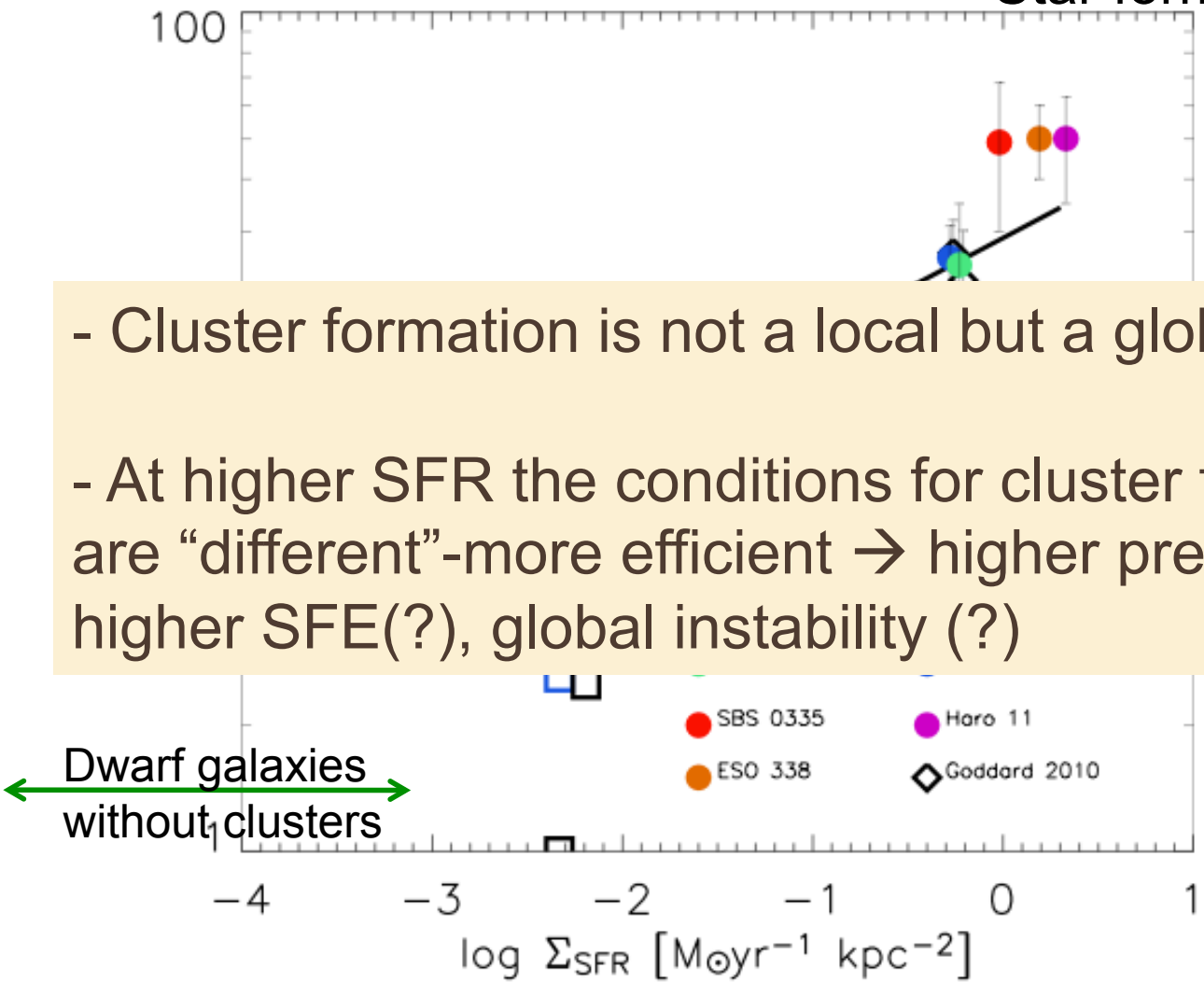
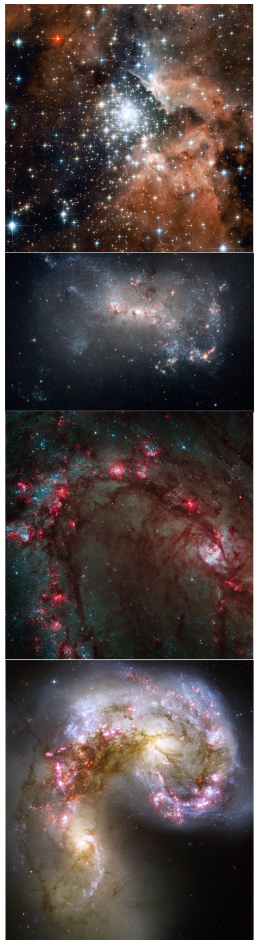




- Cluster formation is not a local but a global event

- At higher SFR the conditions for cluster formation are “different”-more efficient → higher pressure(?), higher SFE(?), global instability (?)

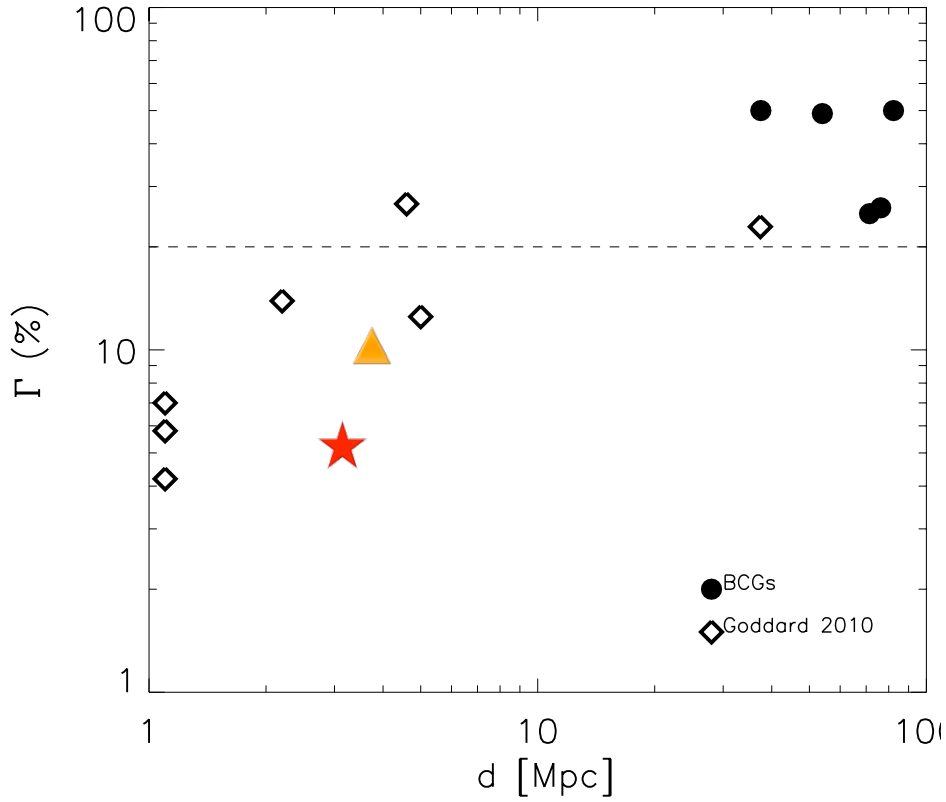
D. Kruijssen’s talk for an analytic fit to the data

Goddard et al 2010, Adamo et al 2011, Silva-Villa&Larsen (2011)

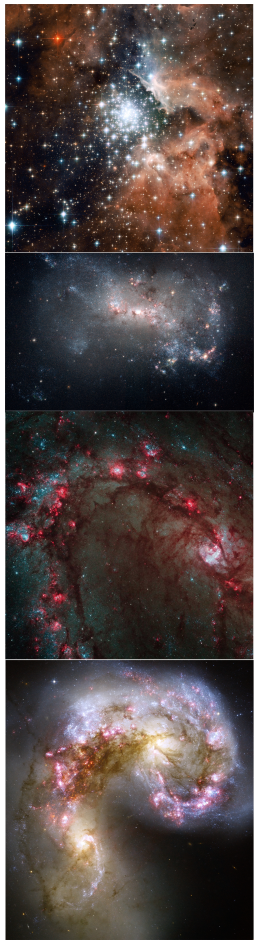
CLUSTER FORMATION EFFICIENCY

- Caveats

1) Cluster detection at larger distances is more challenging → resolution problems, crowding

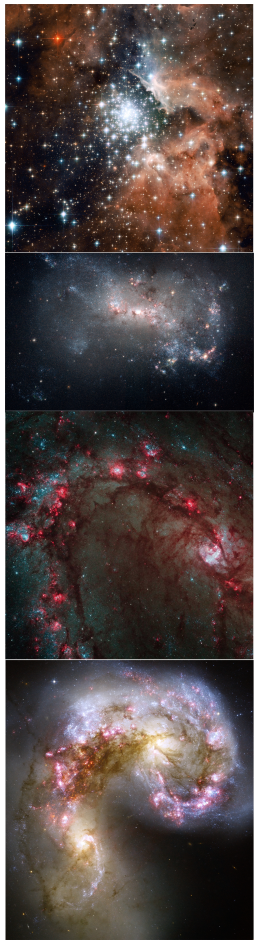


20 %



- Caveats

1) Cluster detection at larger distances is more challenging → resolution problems, crowding
2) different SFR indicators
3) are all the objects clusters? → derived Γ upper limit in some cases



CLUSTER FORMATION EFFICIENCY

SUMMARY

1) Luminous BCGs are ideal systems to study high efficiency of cluster formation (high SFR, low extinction).

2) Cluster formation is not a local event but appears to be tightly related to the global properties of the host galaxies.

3) Not only size-of-sample effects but also environment play an important role on cluster formation.