Seminar Friday 8/24/07
Star Formation: Then and Now

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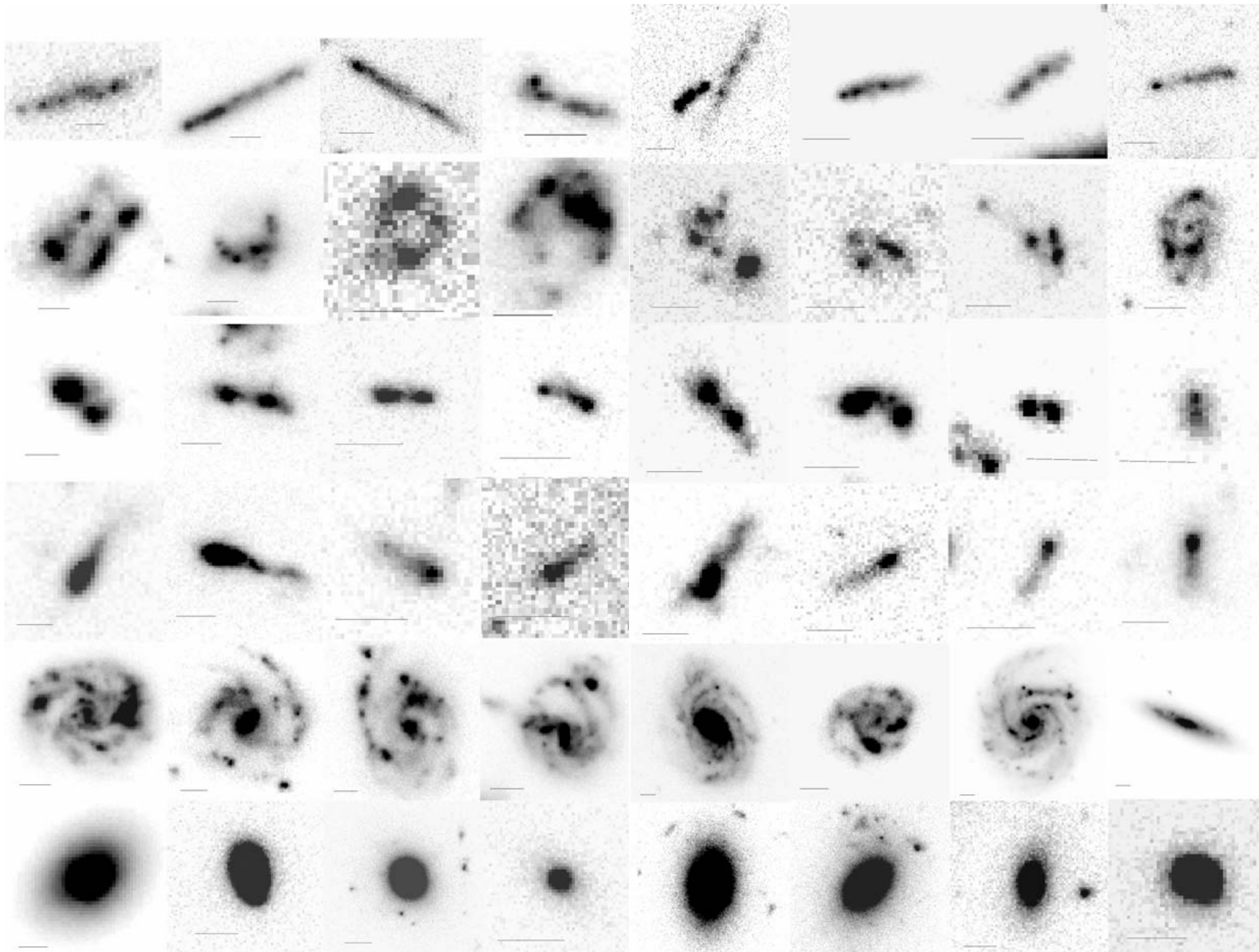
based on a collaboration with Debra Meloy Elmegreen

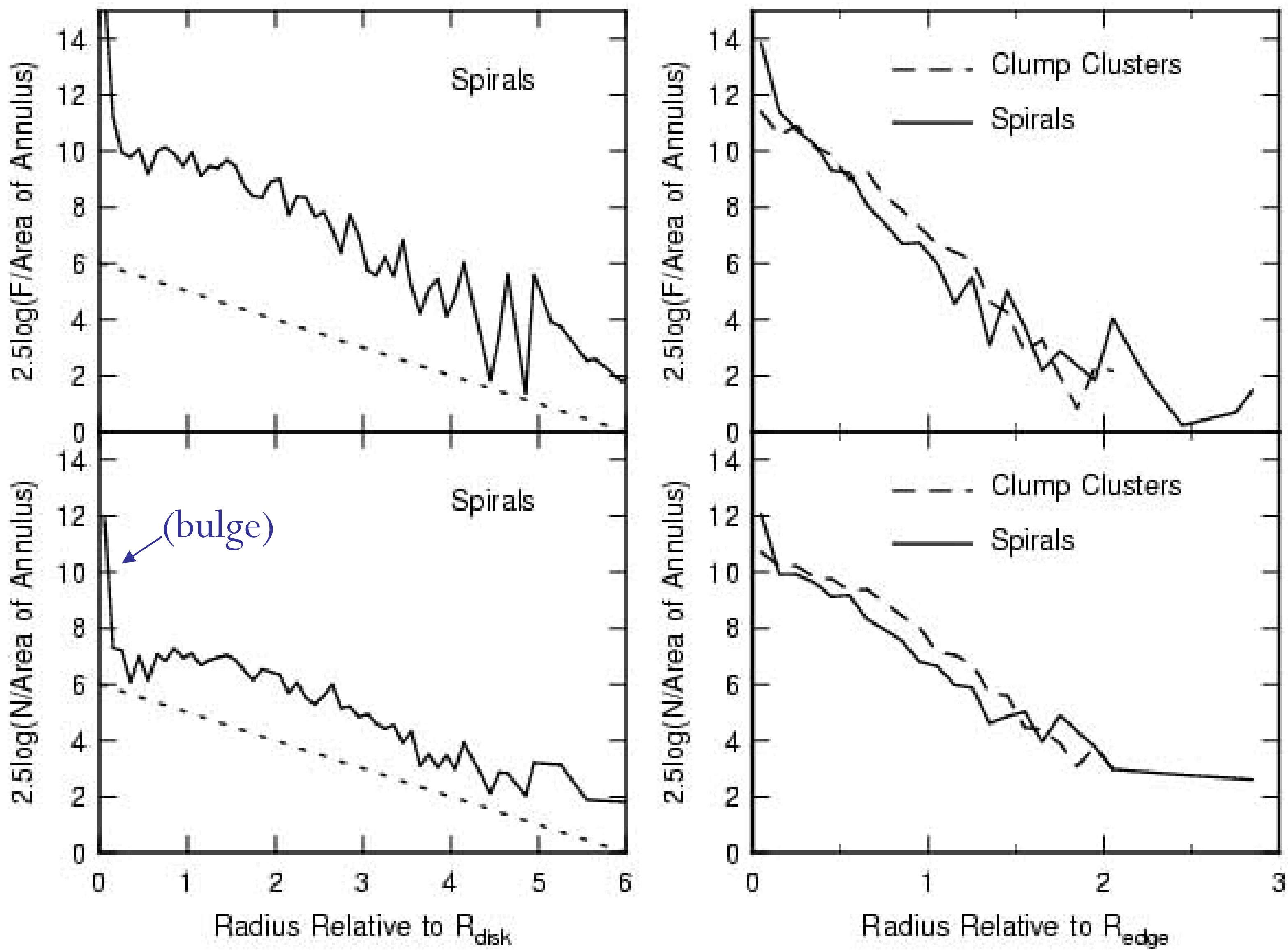
Resolved Galaxies are more clumpy in the UDF

- Chain
- Clump cluster
- Double
- Tadpole
- Spiral
- Elliptical



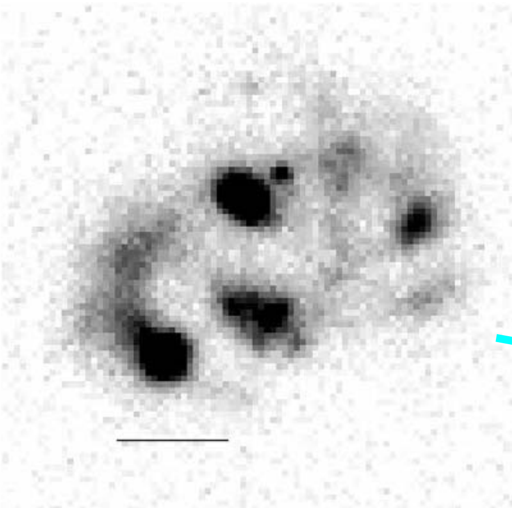
—— = 0.5”

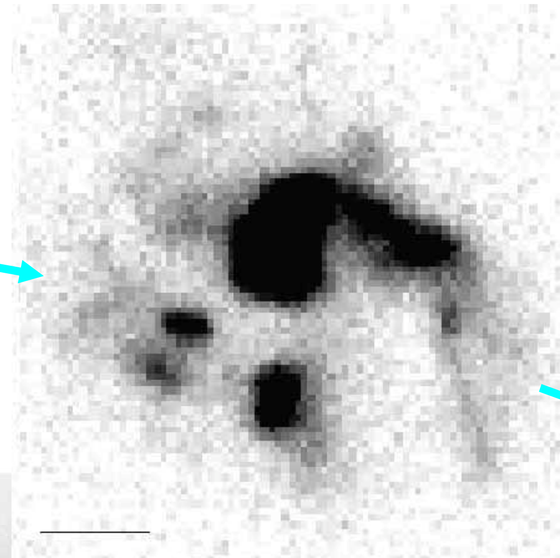
(E,E, Rubin, Schaffer 05)

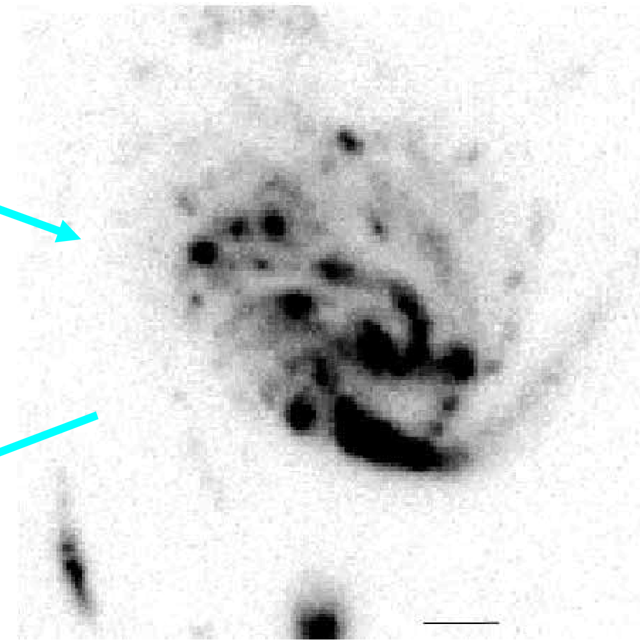


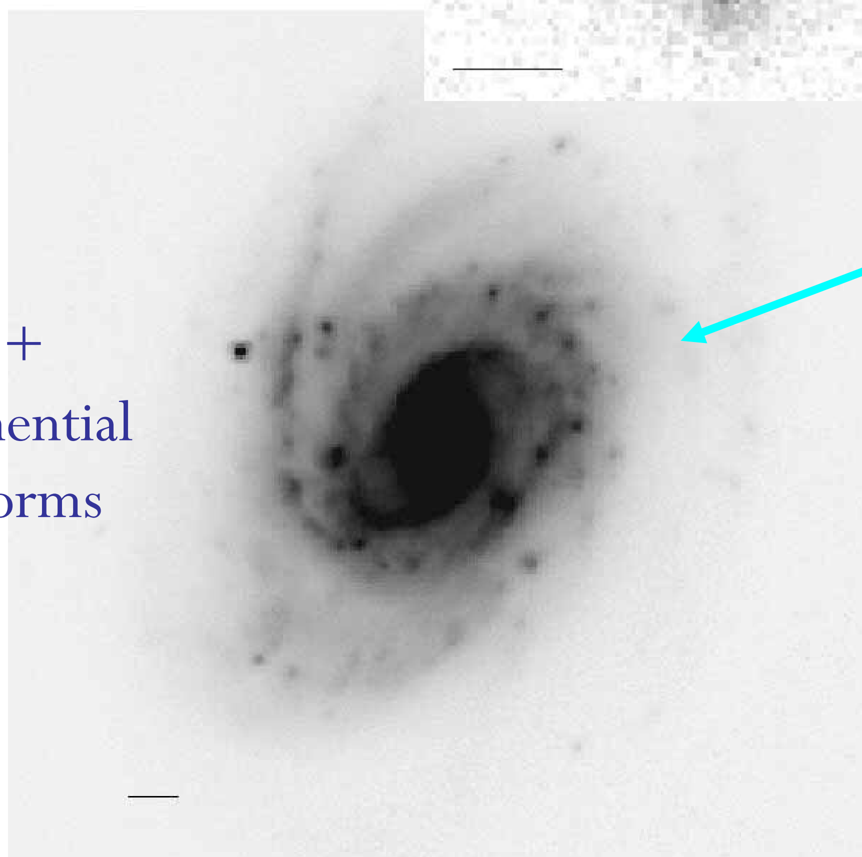
The average radial position of the clumps in the clump-cluster galaxies is exponential, the same as the smooth radial profiles of spirals

(E,E, Vollbach, Foster & Ferguson 05)



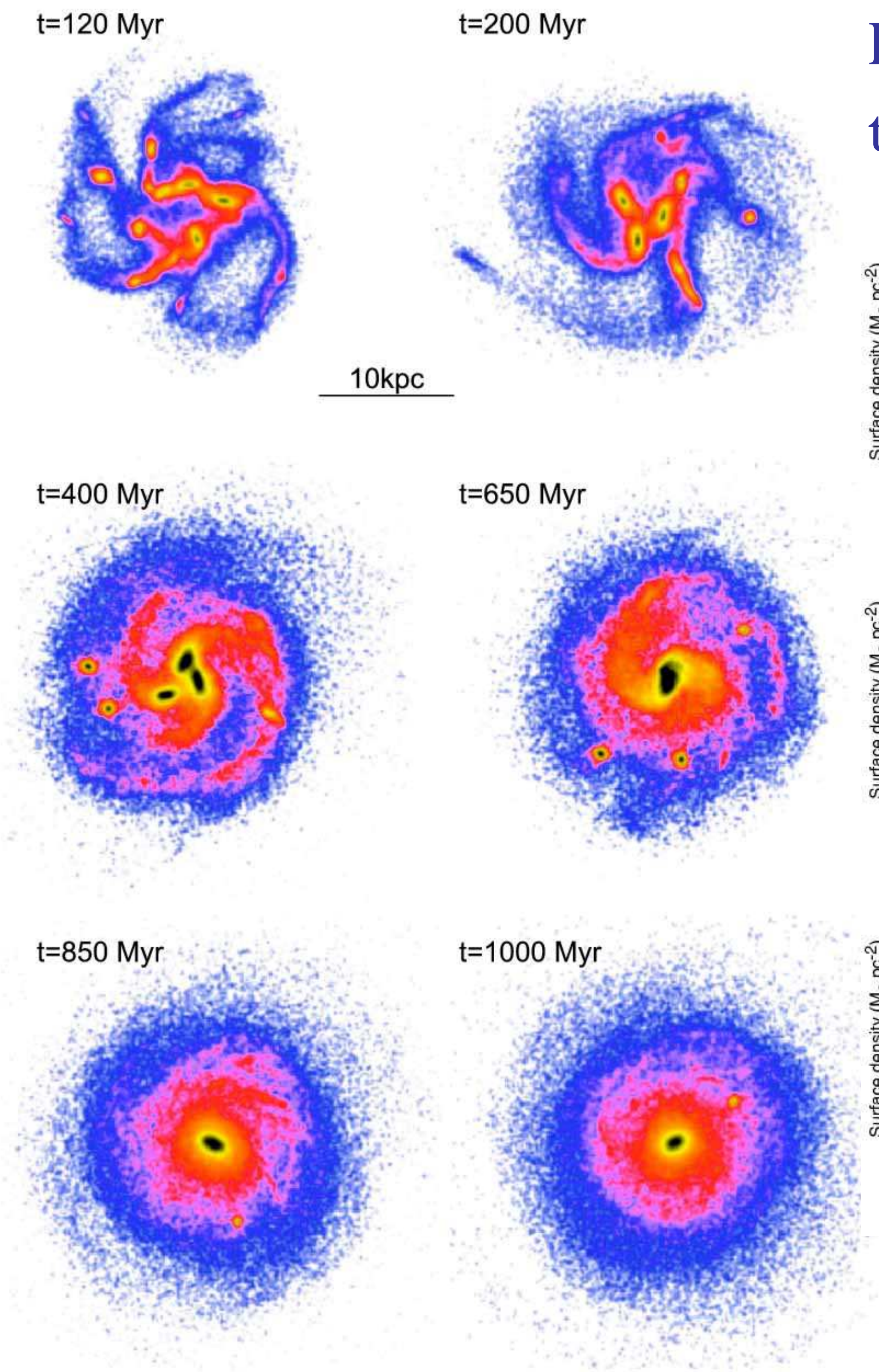




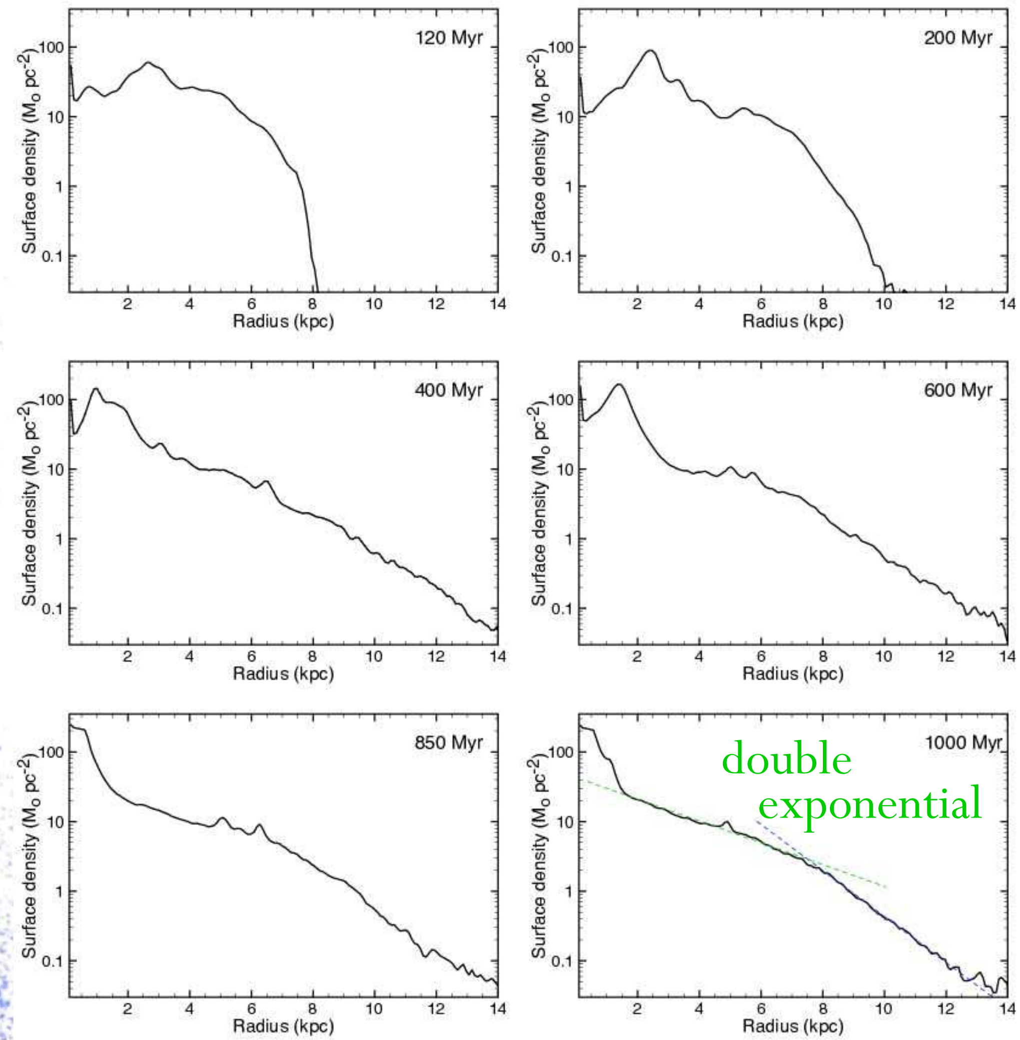


bulge +
exponential
disk forms

Proposed evolutionary sequence as clumps dissolve



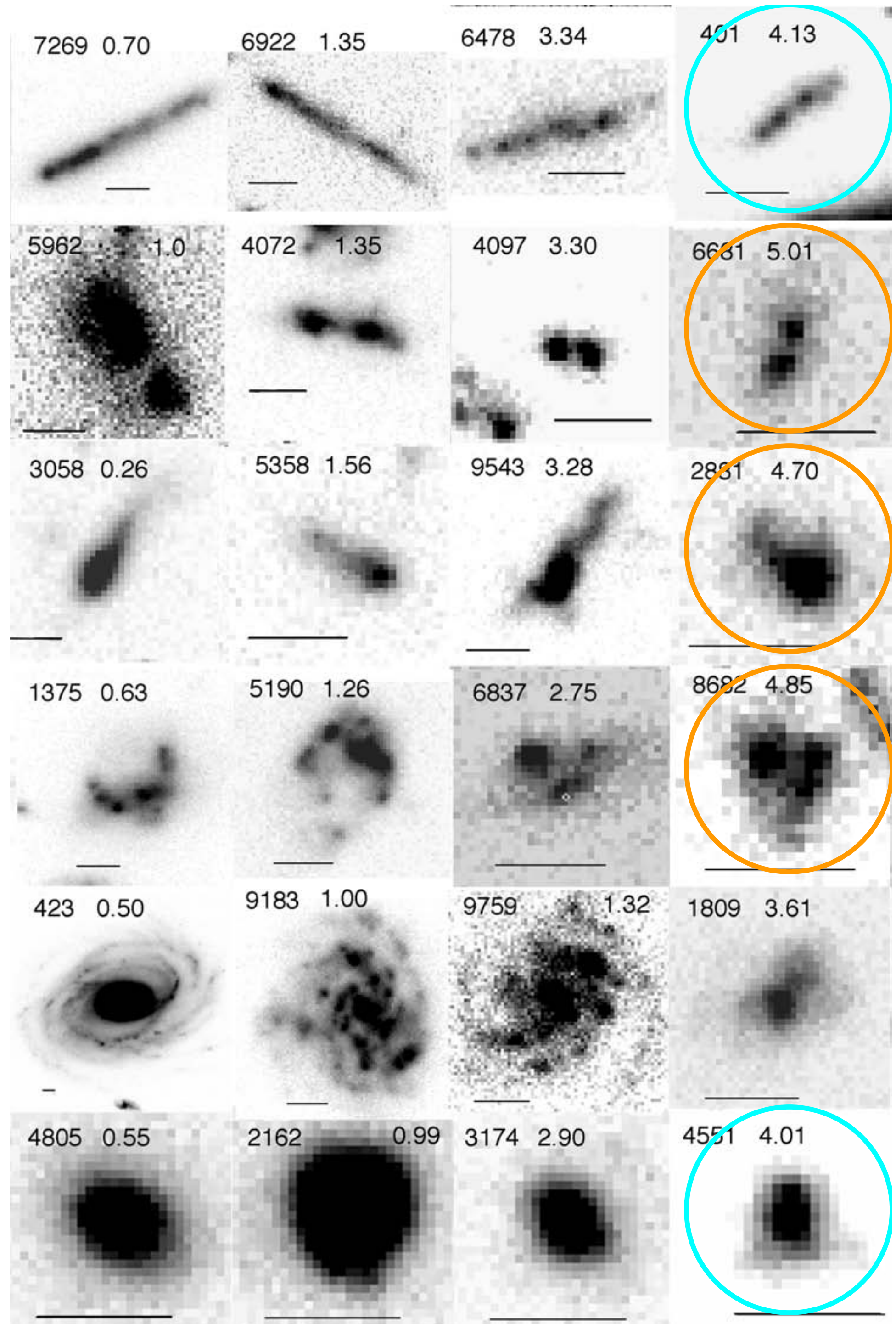
Initially flat disk evolves to a kpc-thick exponential disk with a bulge



Bournaud, Elmegreen & Elmegreen 07

B-band drop outs

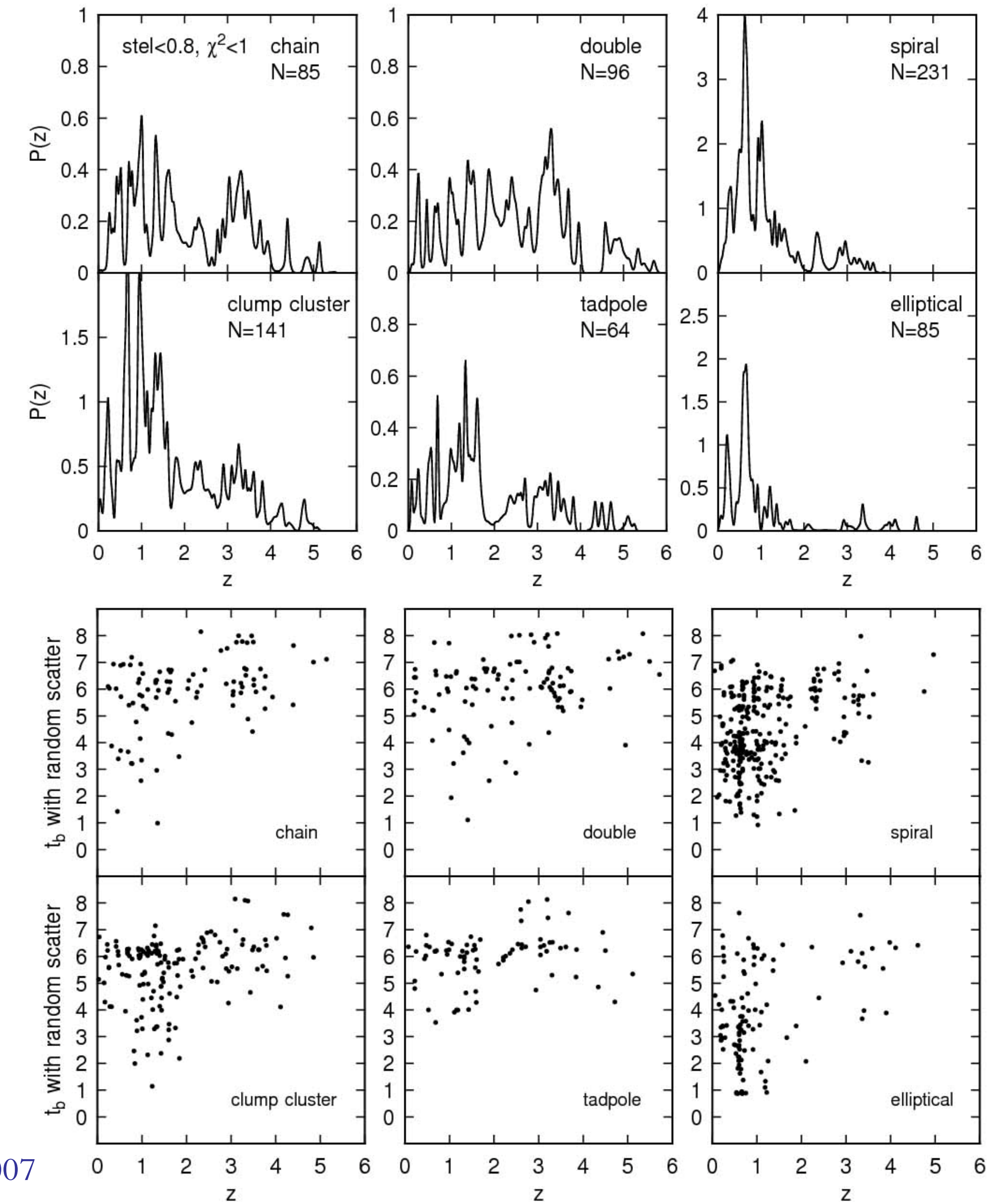
V-band drop outs



Elmegreen, Elmegreen, Ravindranath, Coe 2007a

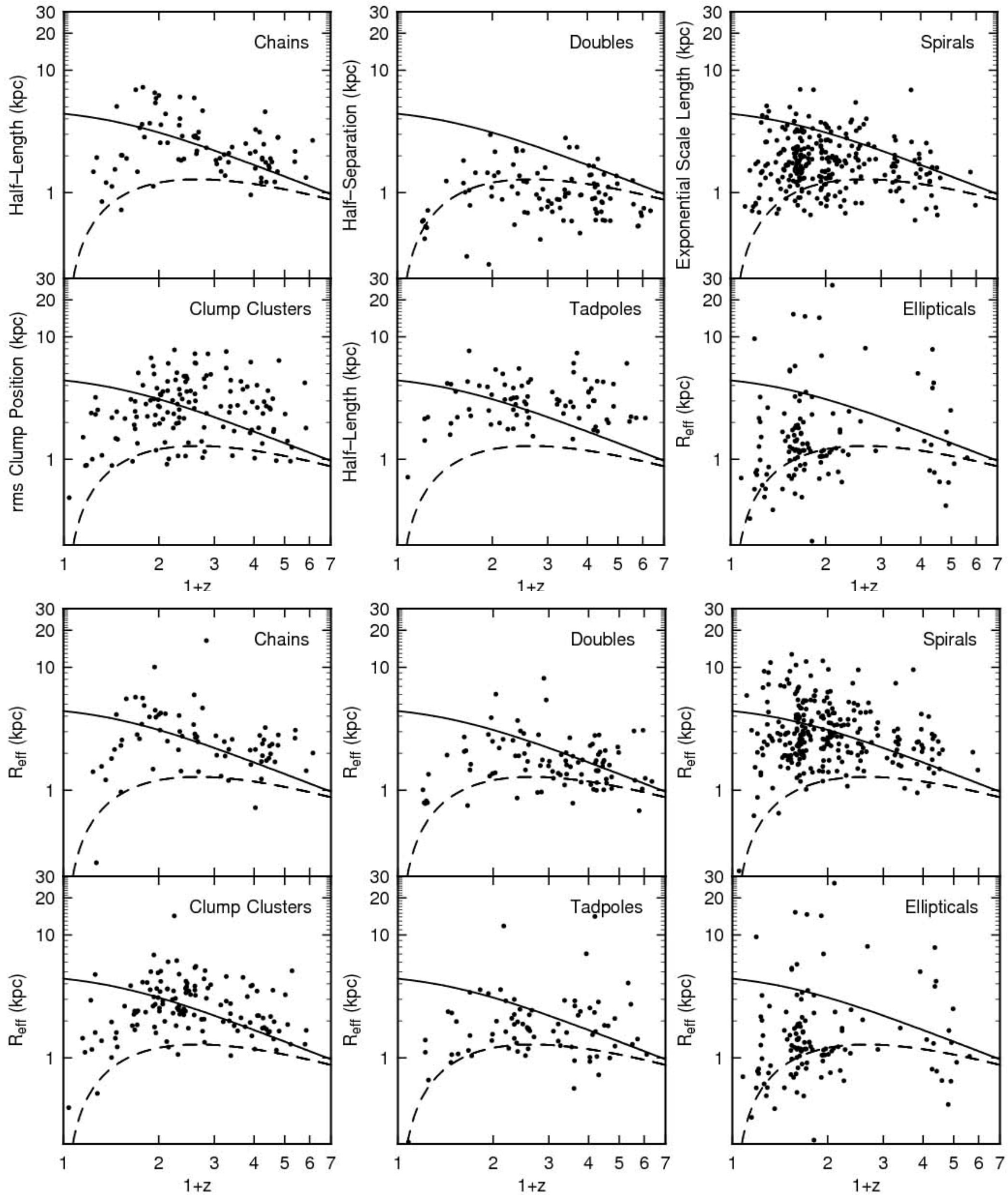
Spirals and Ellipticals restricted to z<2 (a result of bandshifting of red disks out of the ACS z filter)

Clumpy types are highly starbursting and remain visible in the ACS out to z~5. Only the starbursting spirals and ellipticals are visible at z~5.



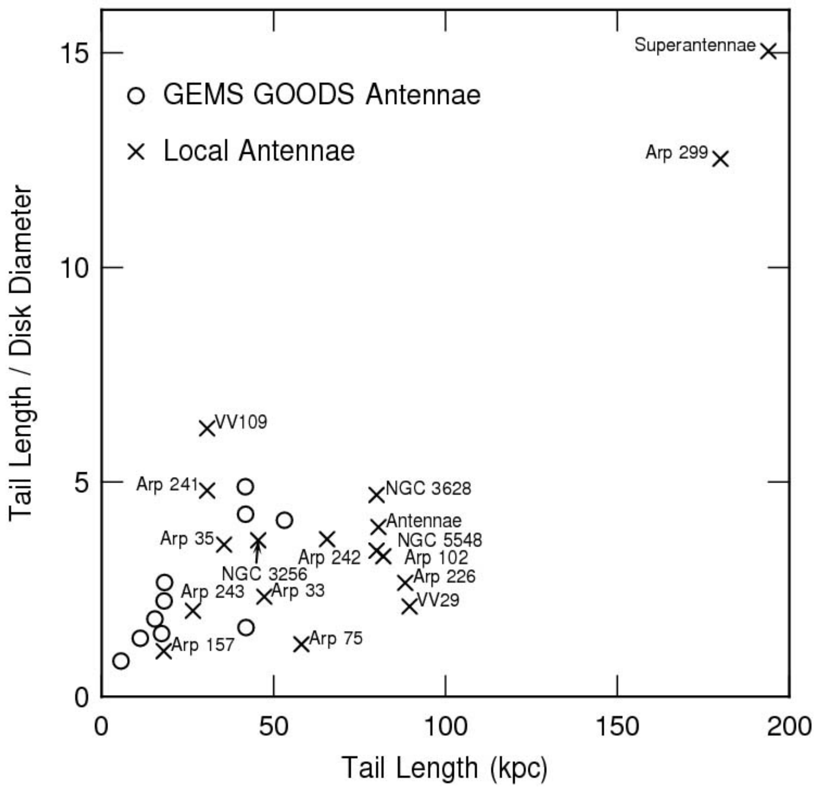
Elmegreen, Elmegreen, Ravindranath, Coe 2007

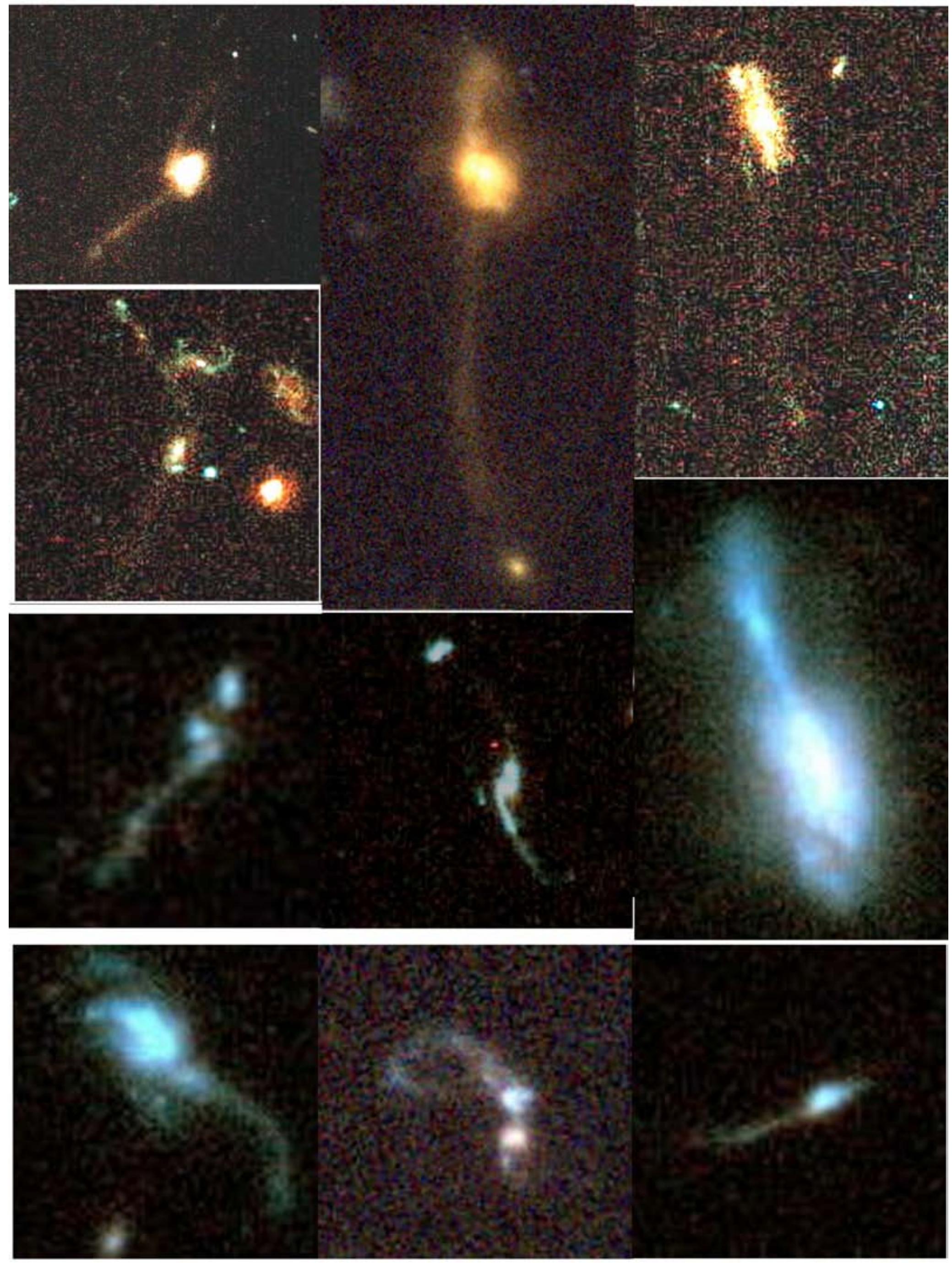
Spirals and Chains get smaller with z. Other types don't show clear evidence for changes here.



Elmegreen, Elmegreen, Ravindranath, Coe 2007

Antennae (GEMS+GOODS) Tidal dwarfs form by GI in the gas (e.g. Wetzstein, Naab, Burkert 07)

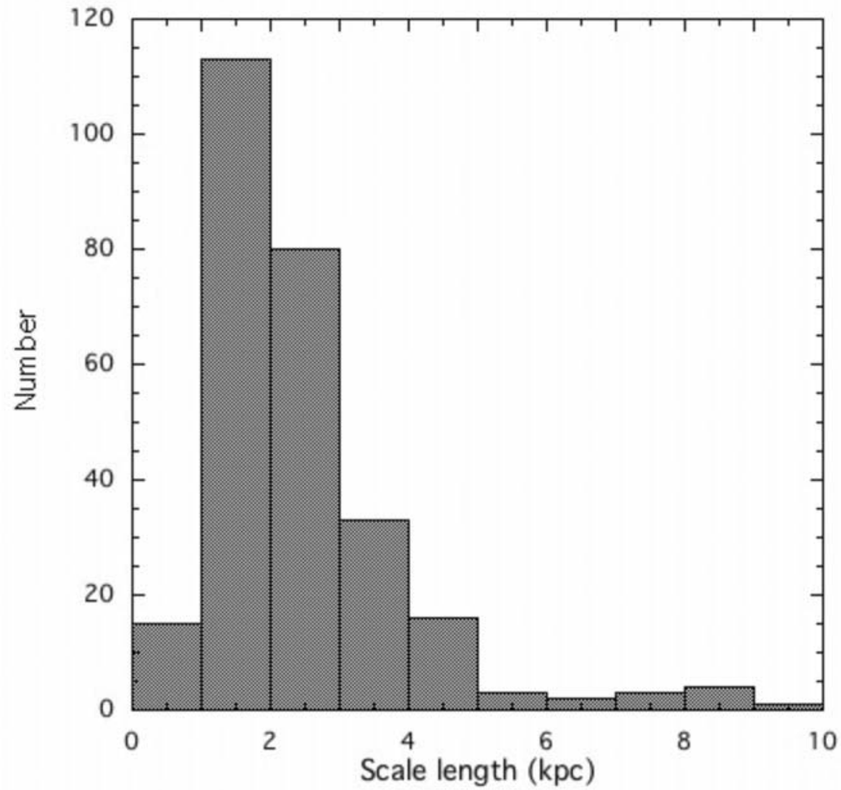




Elmegreen, Elmegreen, Ferguson, Mullan 2007

Linear spiral scale lengths

UDF



Nearby

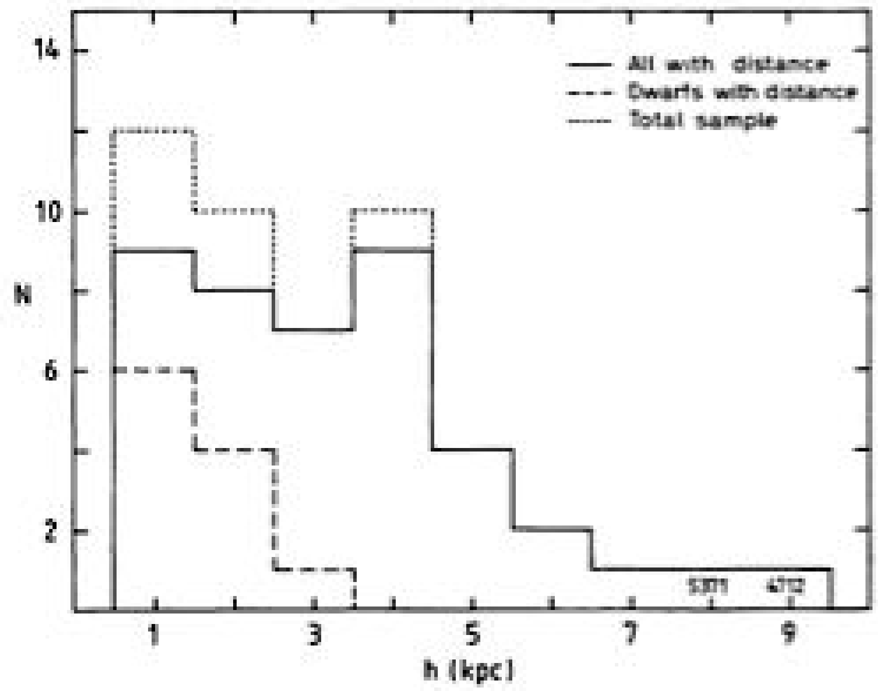
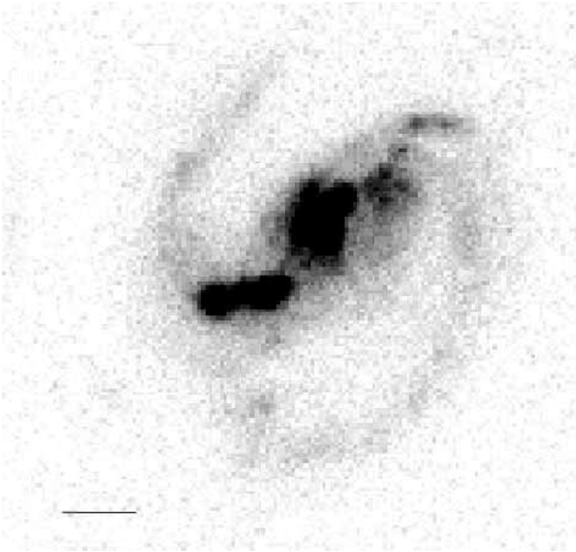


Fig. 8. Histogram of the distribution of scalelengths in the sample. The full-drawn lines refer to the subsample for which radial velocities are available and the dwarfs in this sample have been indicated with the dashed lines. The dotted lines indicate the distribution for the remaining galaxies in the sample using estimated distances. NGC 5371 and 4712 have disks that are only exponential over a small range of scalelength

UDF Spirals are "half size"



- Global spirals imply Toomre length ~ size,
  $2\pi G \Sigma/\kappa^2 \sim R_{disk}$ → small
- Bright disks imply normal or large Σ → κ large
  - κ is proportional to total enclosed density
    → <u>spiral region has high density</u>
- Consistent with theory, $R \sim 1/(1+z)$ (Mo et al. '98)
  - Galaxies form dense inner cores first and grow inside-out
- Also, Toomre length/R_{disk} ~ $M_{disk}/M_{halo}(R<R_{disk})$ ~ 1 to get spirals
  - Galaxies grow ("inside out") as lower and lower-density dark matter+gas is added outside, preserving $M_{disk}/M_{halo} \sim 1$ ($\rho_{gas} \sim \rho_{tidal}$)
- Small UDF <u>spirals will not become today's dwarfs</u> ($M_{disk}/M_{halo} << 1$)
  - need growth of scale length at ~constant M_{disk}/M_{halo}, not just growth in overall size

SF: Yesterday and Today

- SFR peaks higher then
  - still $\sim 0.1\Delta v^3/G \sim 24(\Delta v/100\ km/s)^3\ M_O/yr$
    - dynamical rate with efficiency
  - higher then because more gas in high Δv galaxies
    - downsizing makes high Δv galaxies gas-free today
- Interactions make higher SFR than quiescent galaxies
  - Δv higher (quiescent: Δv^2 from rotation, Δv^1 from turbulence; whereas interaction Δv^3 from rotation)
    - for 2D relaxed: total $SFR=0.1\rho(G\rho)^{1/2}\pi R^2 H=0.1(GM/R)(\rho/G)^{1/2}H$ $=0.1Dv^2 a/G=2.4(\Delta v/100\ km/s)^2(a/10\ km/s)$

- Galaxies were smaller, denser then (R factor of 2, ρ factor of ~4)
  - SF proceeds inside out in a galaxy
  - galaxies had faster SF rates on average, but only like the inner parts of disks
  - plus other galaxies, now dead, had much higher SF rates
  - consistent with Q~1.5 equilibrium always (clump cluster models also Q~1.5)
- SF clumps were bigger then ($10^{8.5}$ M_O compared to $10^{5.5}$ M_O)
  - today's clumps: "star complexes" (Efremov), "GMA's", "superclouds"
  - then: 2 M_O/yr for clump ~ 2 M_O/yr/kpc^2: factor of 100 times MW
    - radiation field inside SF region then = 100x today
  - then: average density in SF region: 5 cm^{-3} (like today's superclouds)
    - therefore t_{dyn}~40 My < age (which is ~300 Myr; note t_{decay}~100My~2.5t_{dyn})
    - $t_{dyn} * V_{rot}/R_{gal}$ ~ 0.3, which means $\rho_{tidal}/\rho_{clump}$ ~ 10 (marginally bound)
  - then: M,R of clump give Δv~25 km/s, so $\rho\Delta v^2 \sim 4\text{x}10^5 k_B$ (40x local kpc-scale)
  - then: radiation field U=100xlocal means T_{dust}=2.5xlocal, P=40xlocal means MJ ~ $T^2/P^{0.5}$ ~ 6/6 ~ same as local!
- $\Delta v > a_{HII}$ so no triggering by expanding HII regions? possibly also implies higher efficiency for clusters via lesser ability to disrupt clouds