Environmentally or internally driven evolution of galaxies

A room with a view...

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- Identifying mergers with kinematical information / numerical simulations
- Role of mergers in the morphological evolution of galaxies
- Role of mergers in the star formation history
- In the local and distant Universe

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Results from galaxy/cosmology group of AIM, CEA-Saclay:

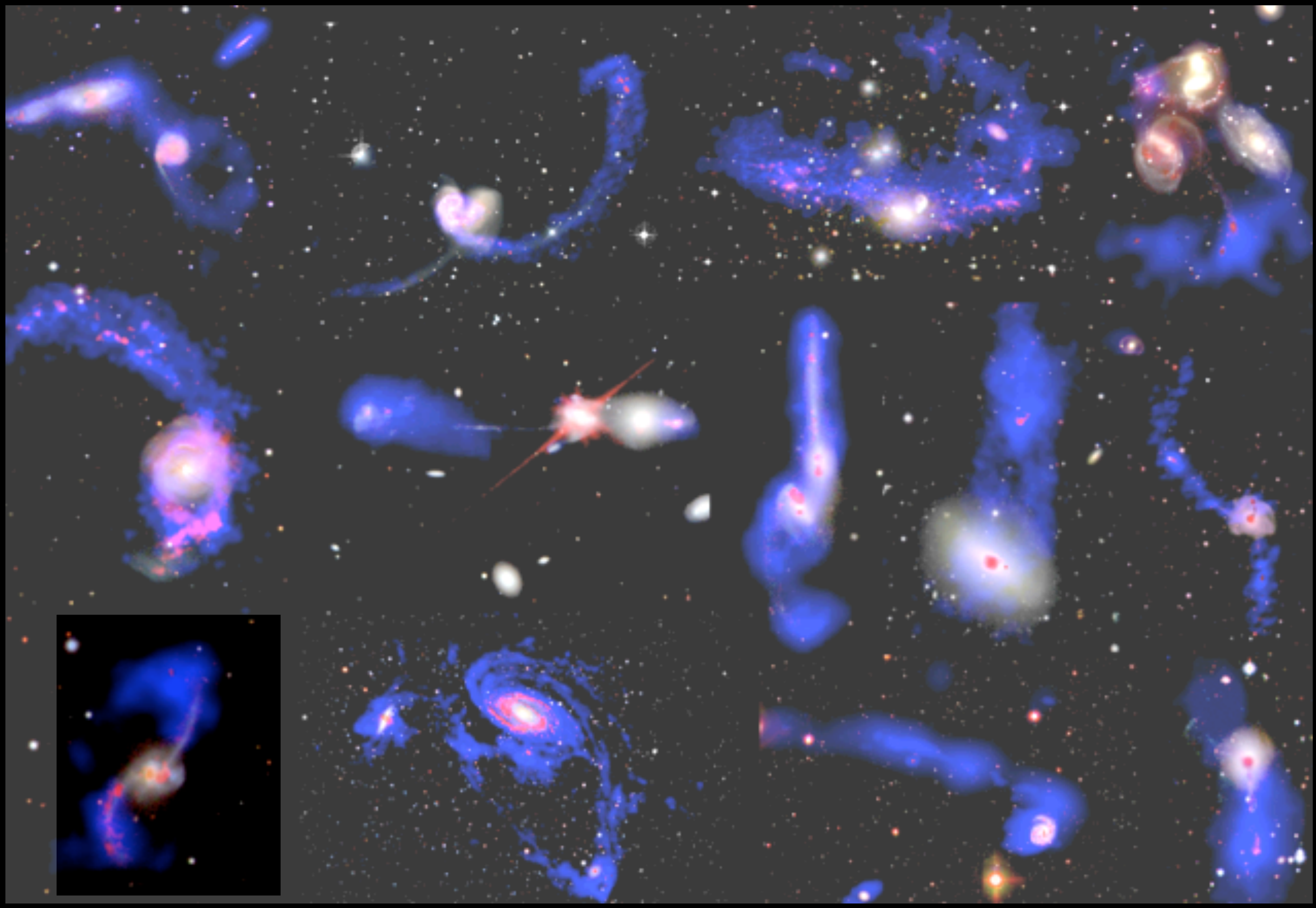
Frédéric Bournaud
Emmanuele Daddi
David Elbaz

Bruce Elmegreen, IBM
Debra Elmegreen, Vassar College
Nicole Nesvadba, IAS
Paola Di Matteo, Obs Paris

Mergers in the local Universe

Mergers in the local Universe

Mergers in the local Universe



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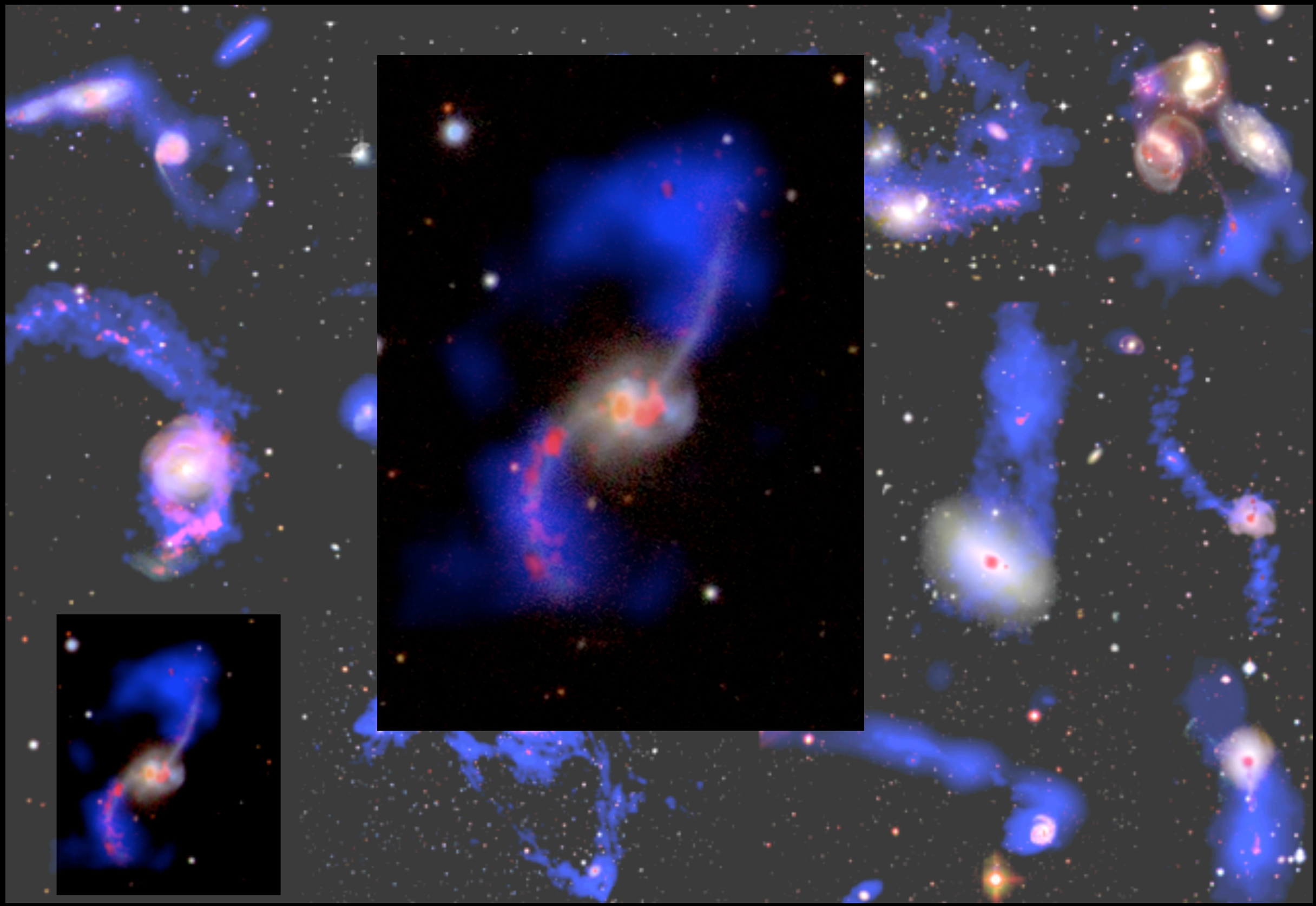

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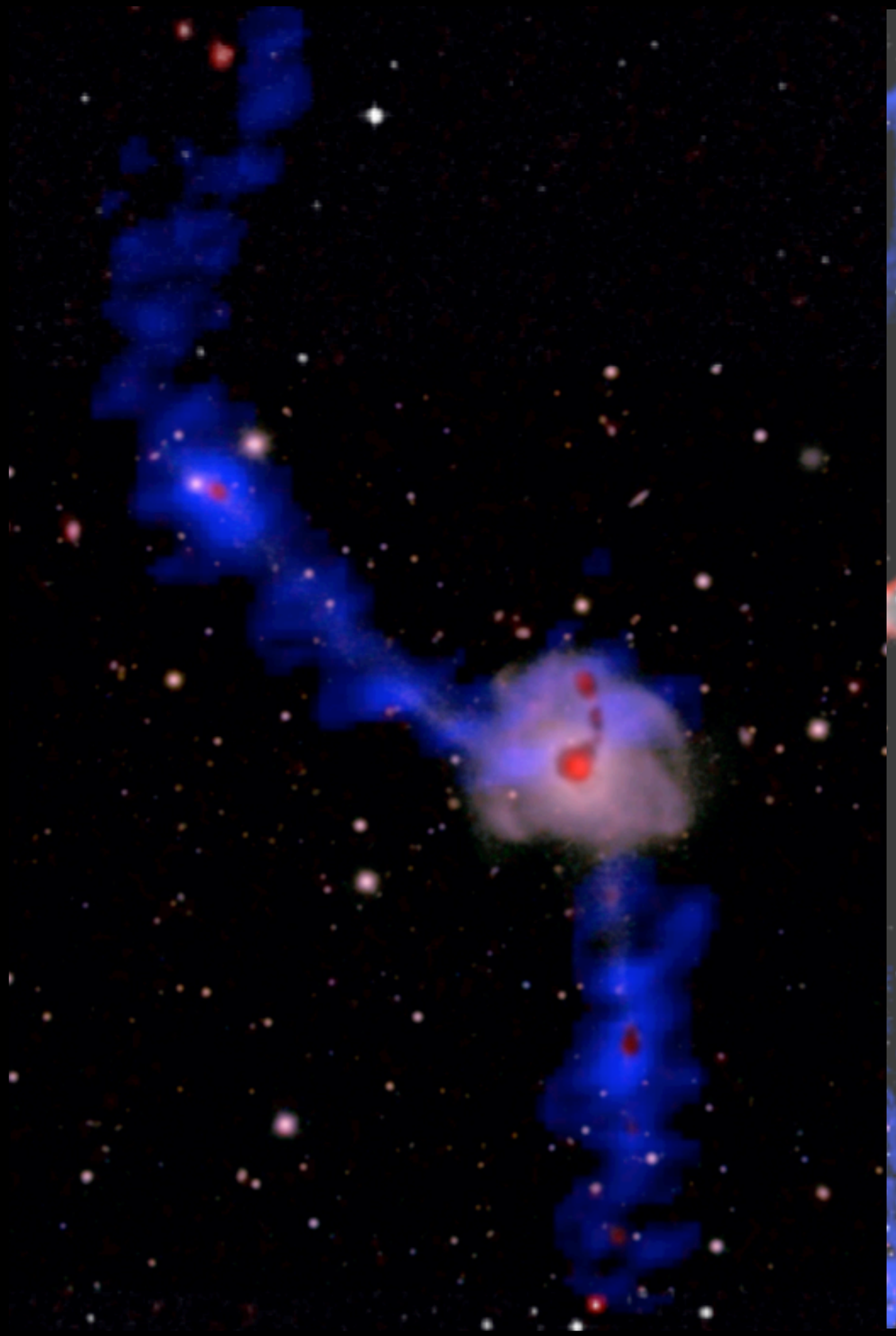

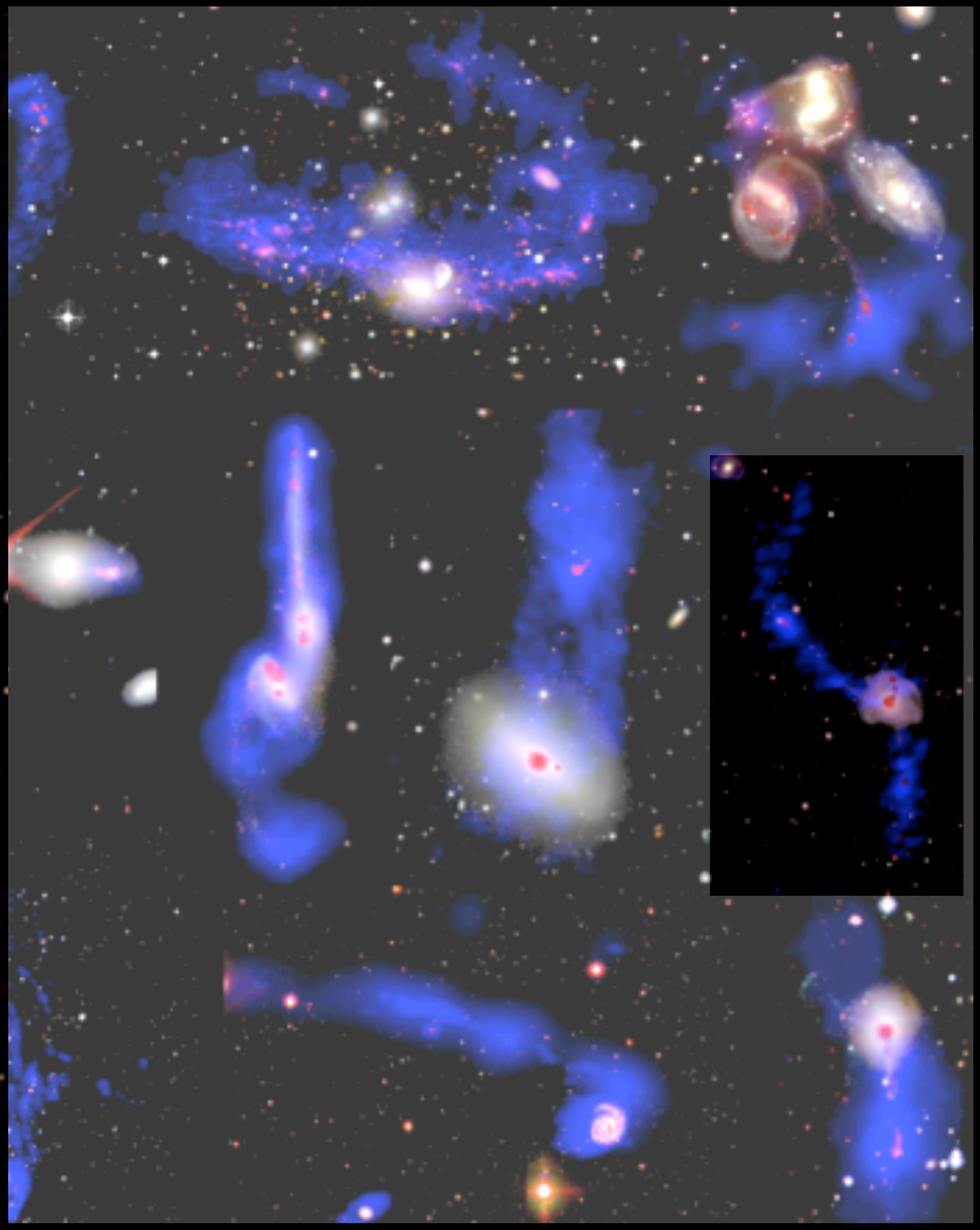

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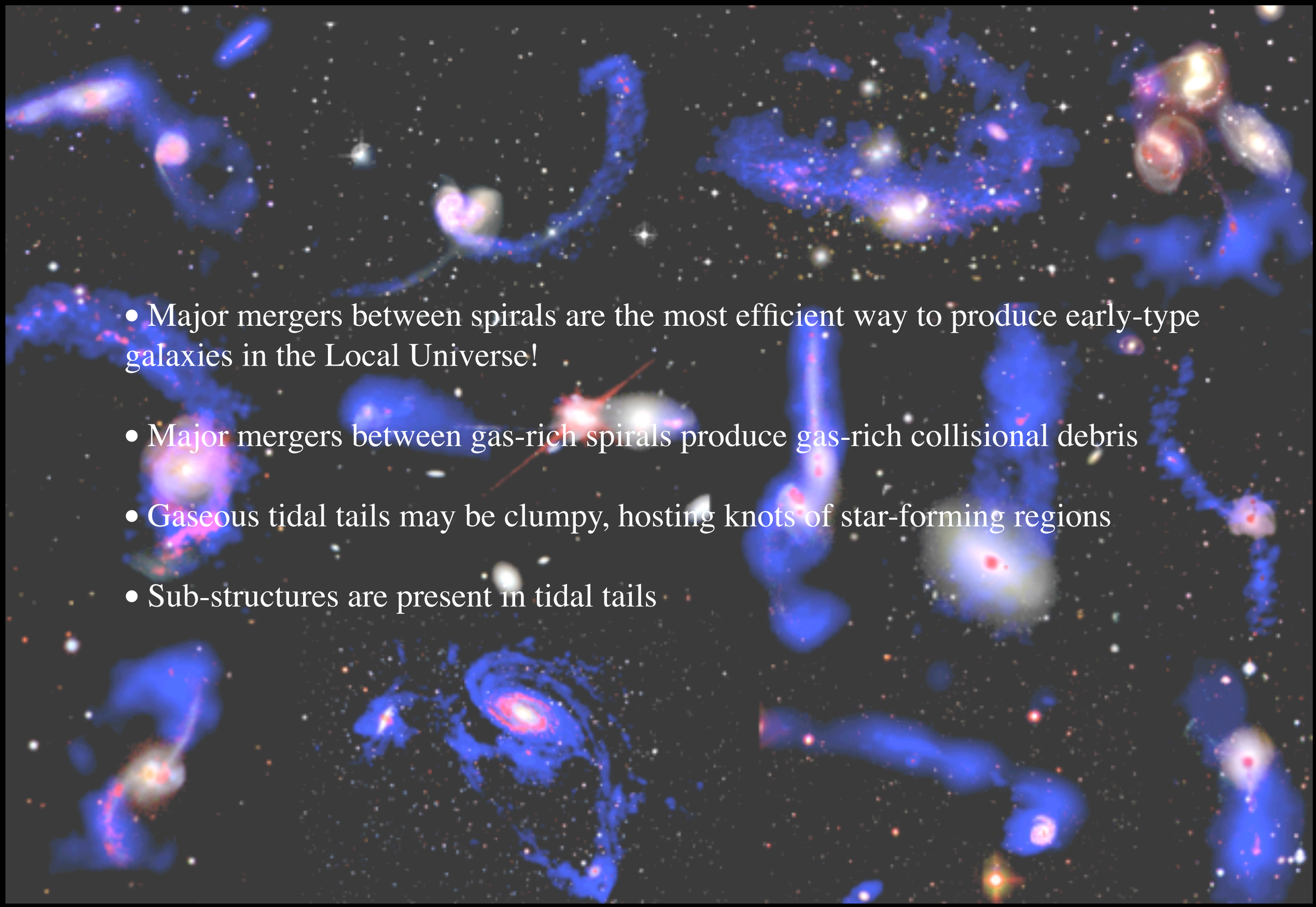

- Major mergers between spirals are the most efficient way to produce early-type galaxies in the Local Universe!
- Major mergers between gas-rich spirals produce gas-rich collisional debris
- Gaseous tidal tails may be clumpy, hosting knots of star-forming regions
- Sub-structures are present in tidal tails

Mergers in the local Universe

Formation of sub-structures
within tidal debris

Bournaud, Duc & Emsellem, 2008

Formation of sub-structures within tidal debris

✓ Compact Super Star Clusters

Bournaud, Duc & Emsellem, 2008

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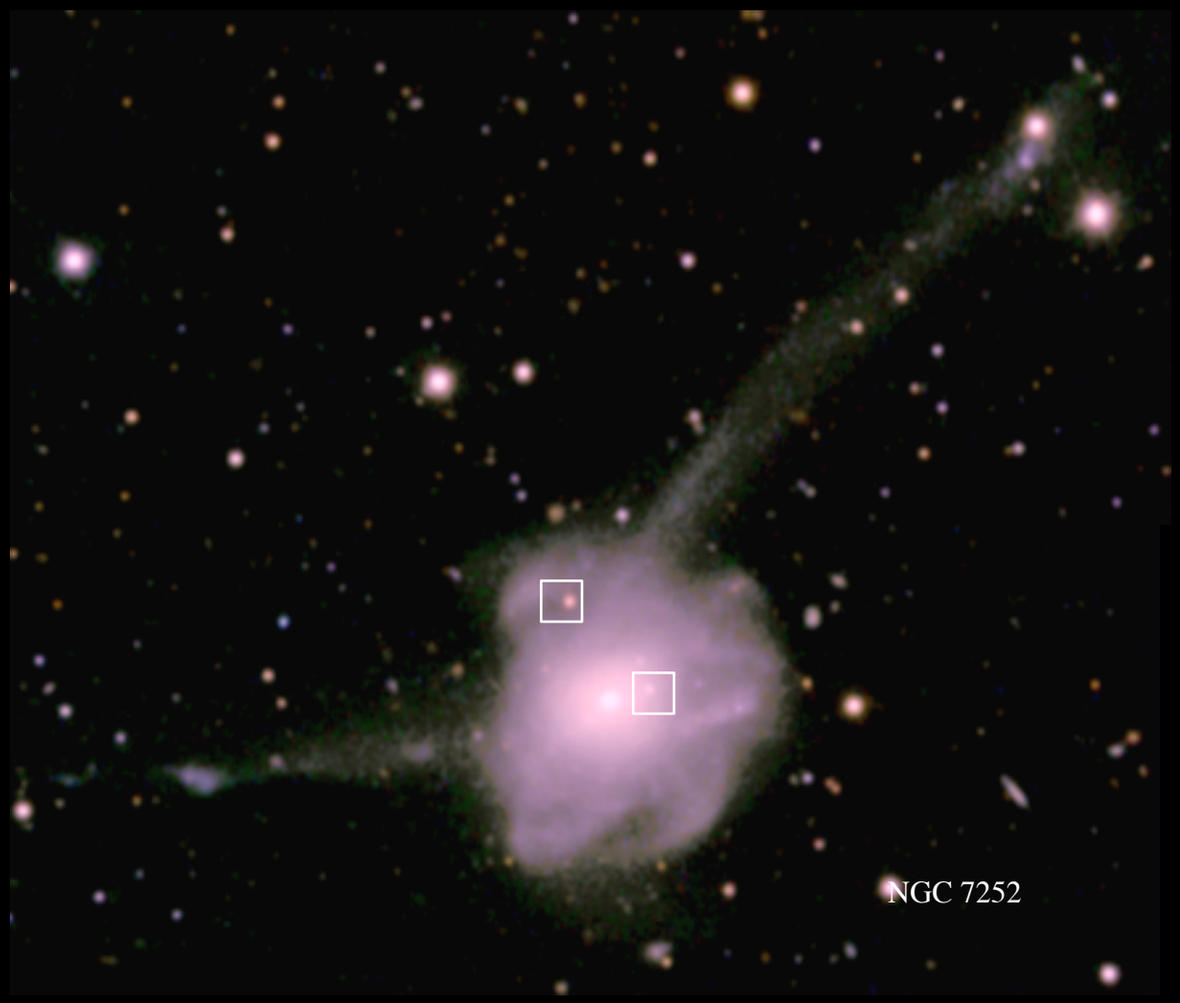

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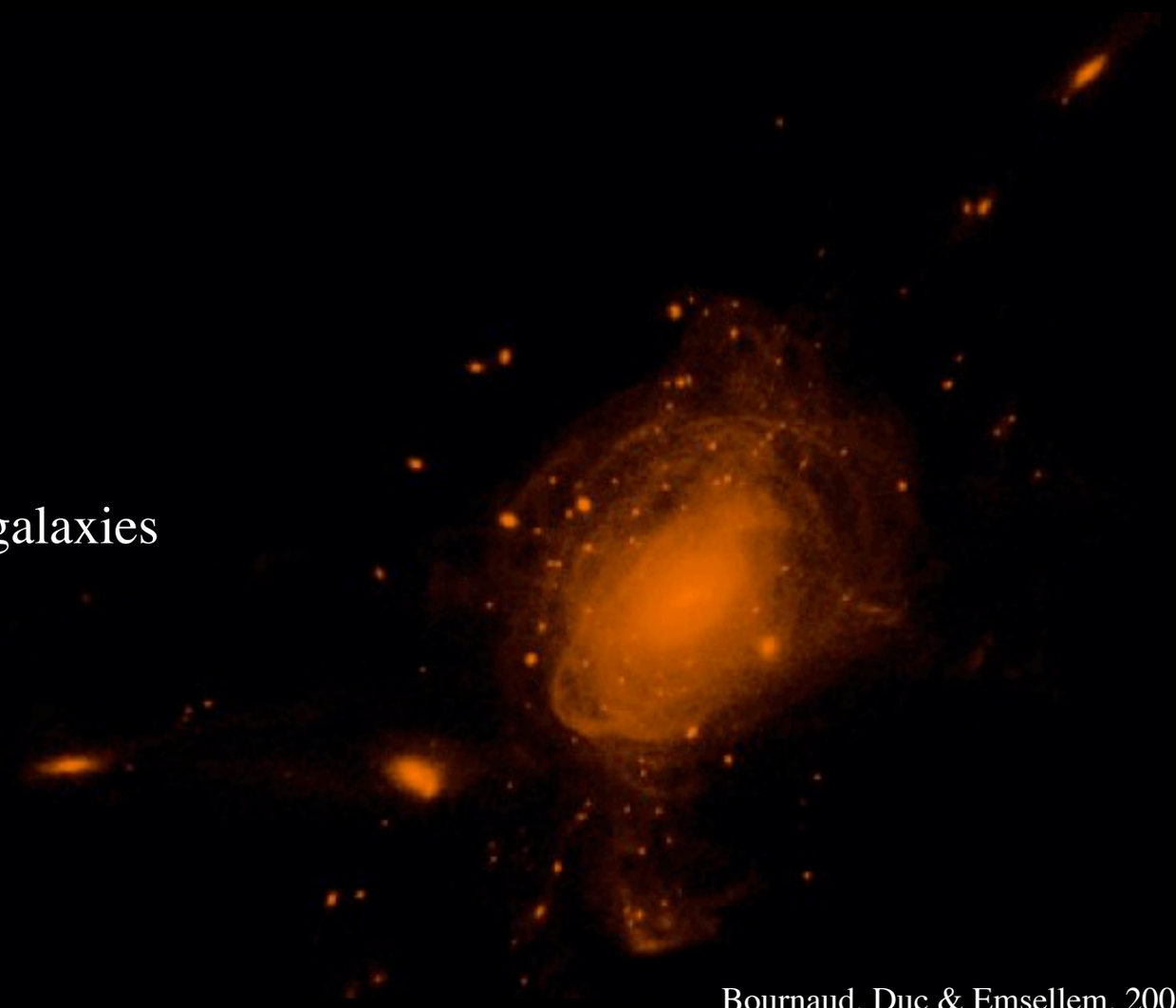
✓Tidal dwarf galaxies



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Mergers in the local Universe

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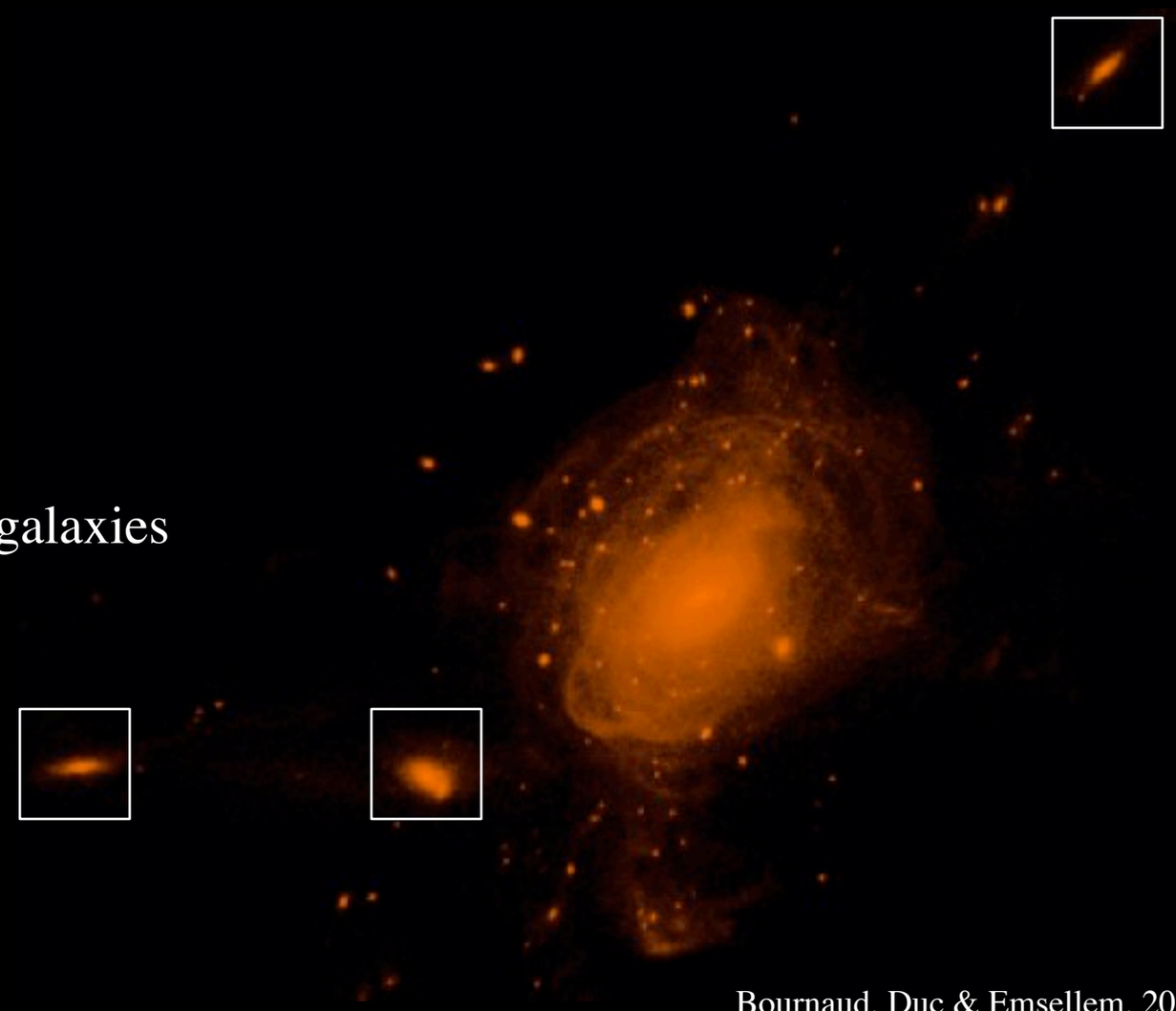

Bournaud, Duc & Emsellem, 2008

Mergers in the local Universe

Formation of sub-structures within tidal debris

NGC 7252

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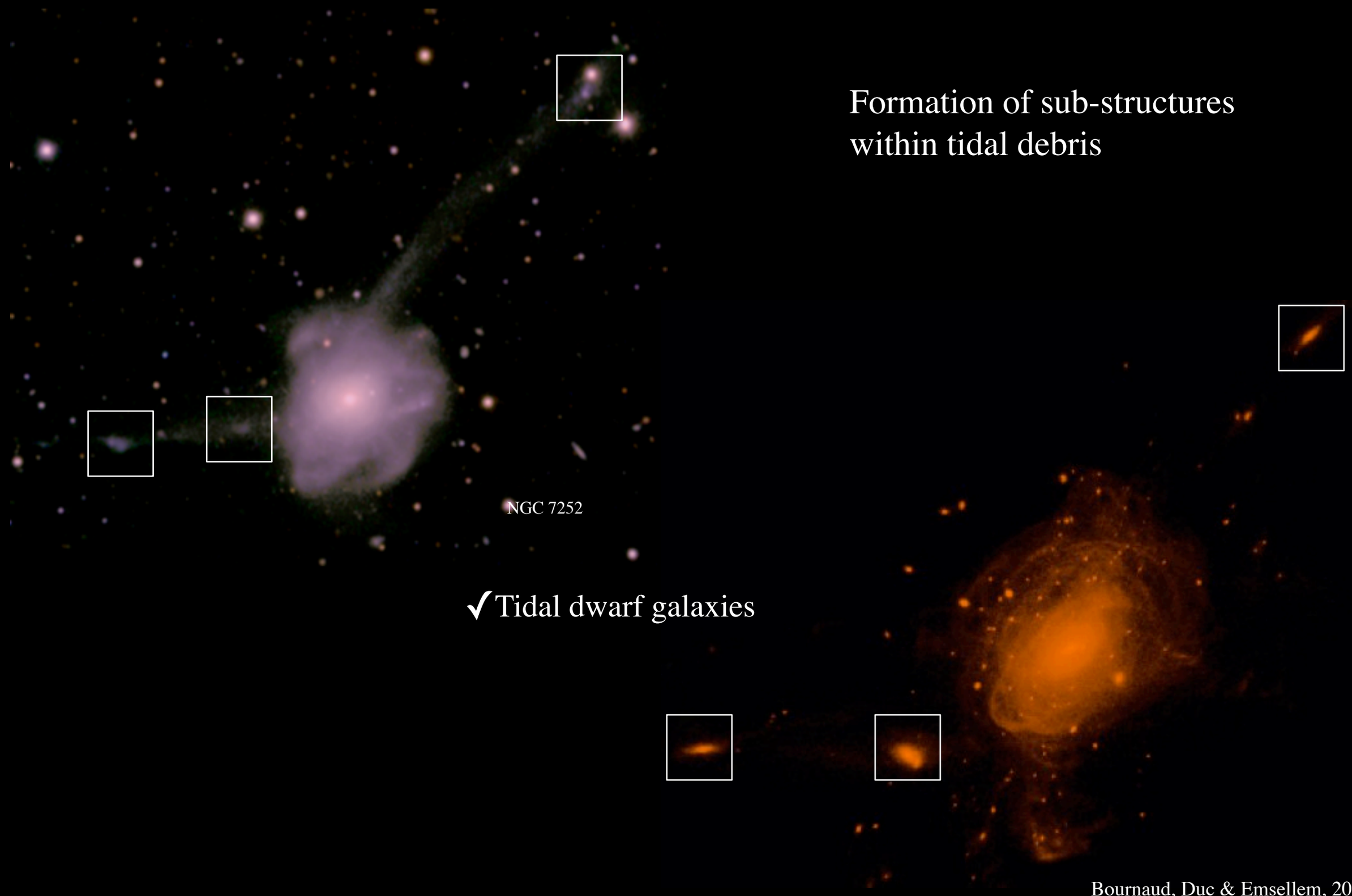
Bournaud, Duc & Emsellem, 2008

Mergers in the local Universe



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Mergers in the local Universe

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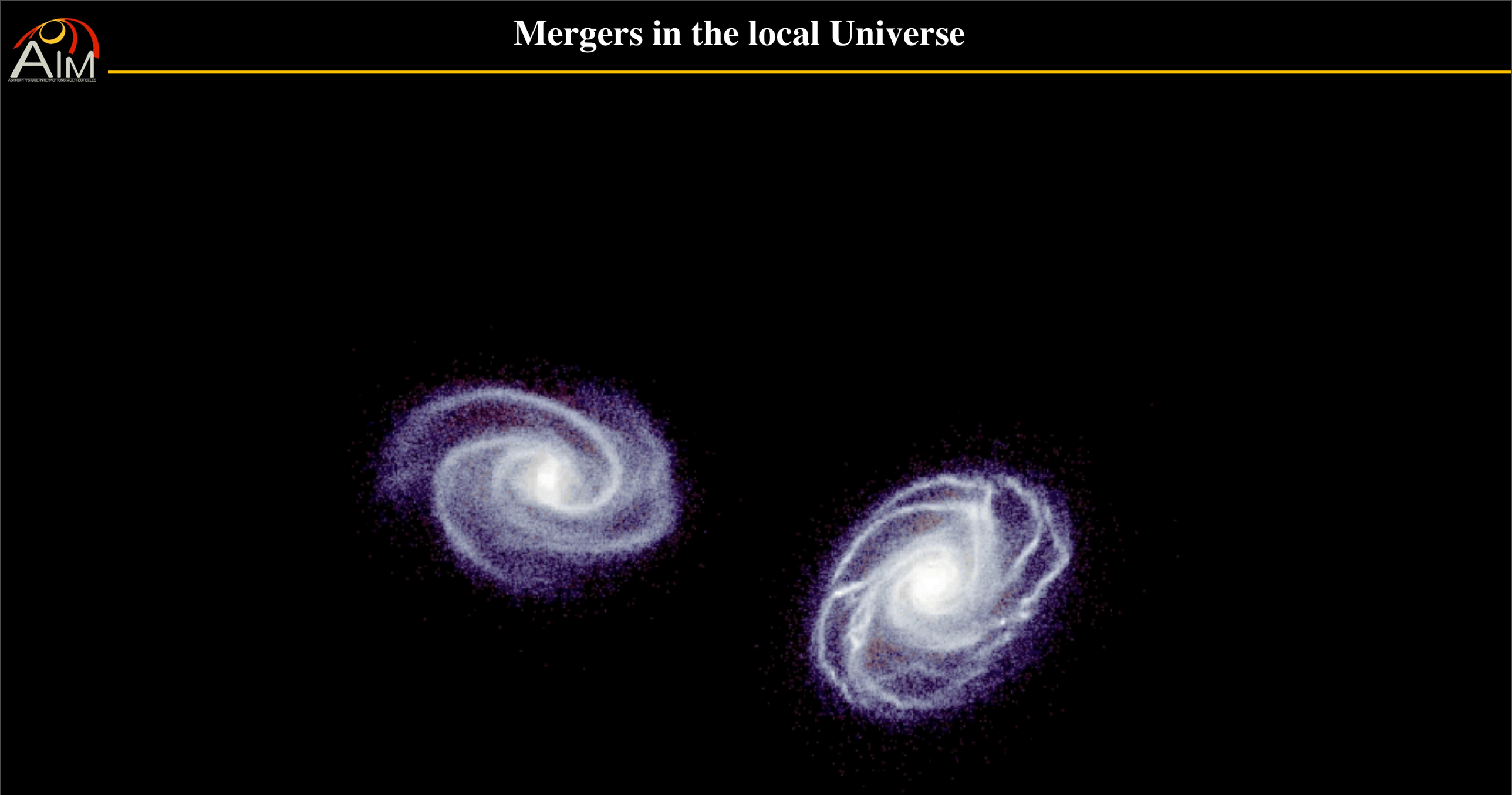
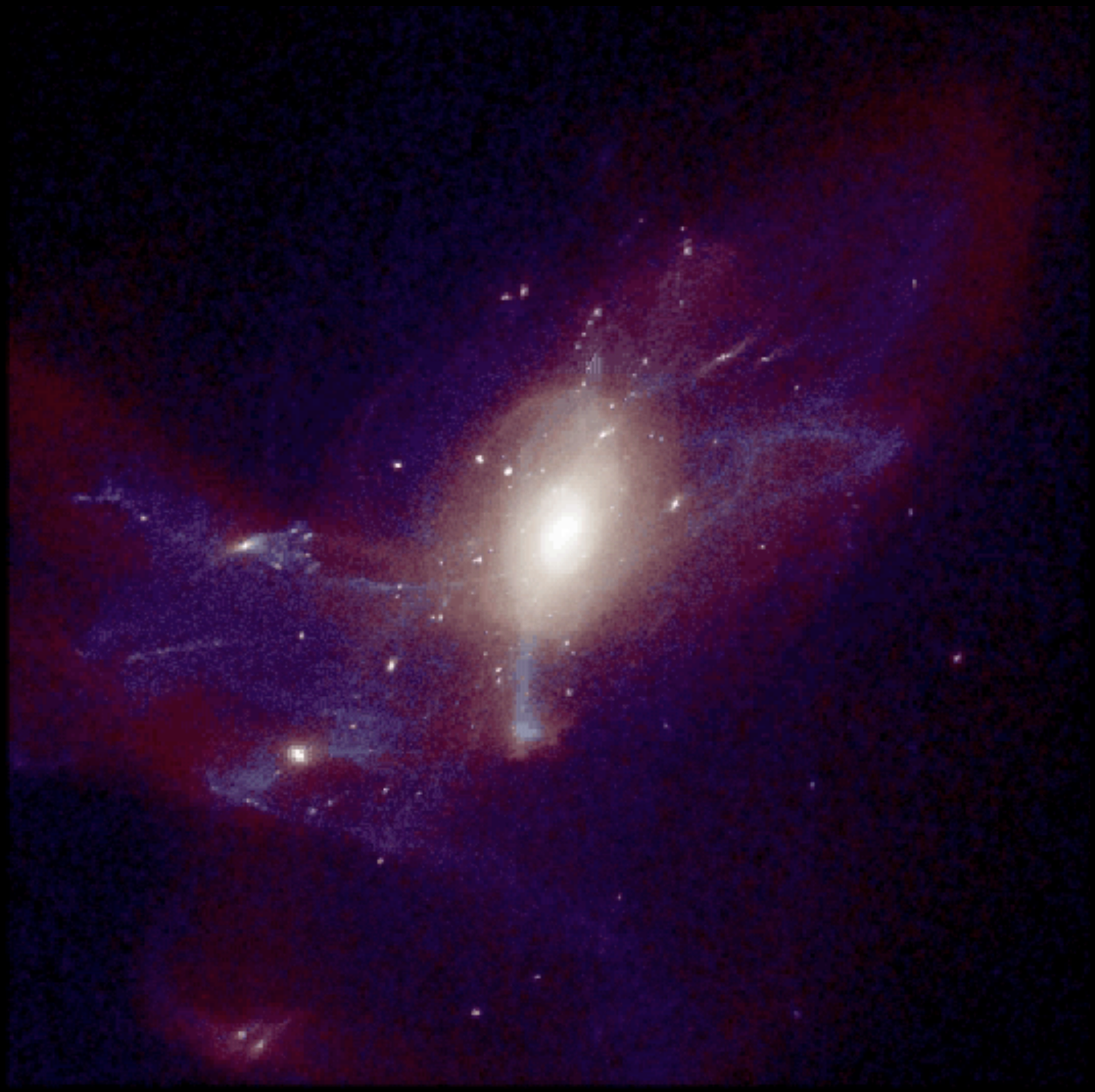


Mergers in the local Universe

After 1 Gyr

Bournaud, Duc & Emsellem, 2008

Mergers in the local Universe



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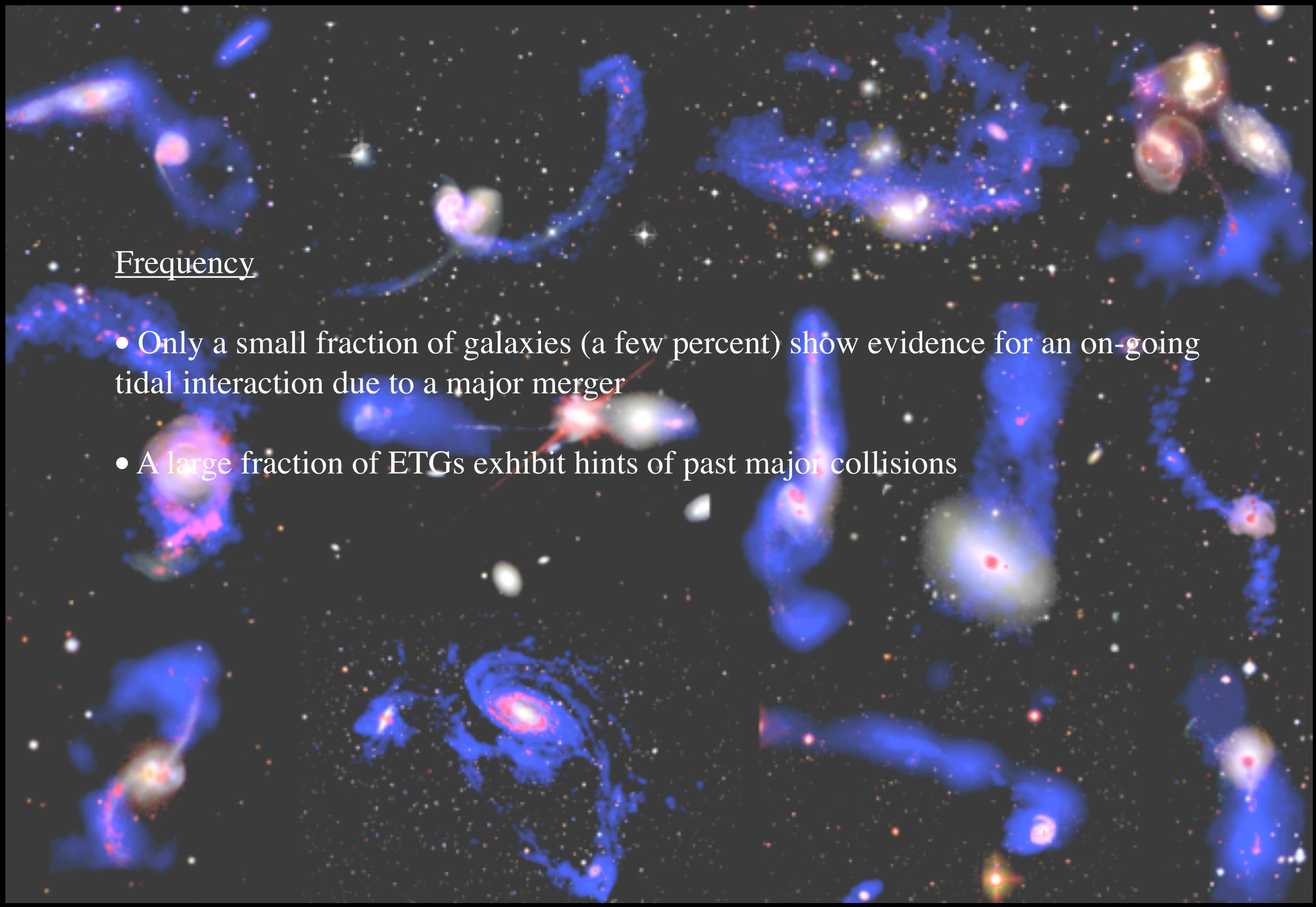
Bournaud, Duc & Emsellem, 2008

Mergers in the local Universe

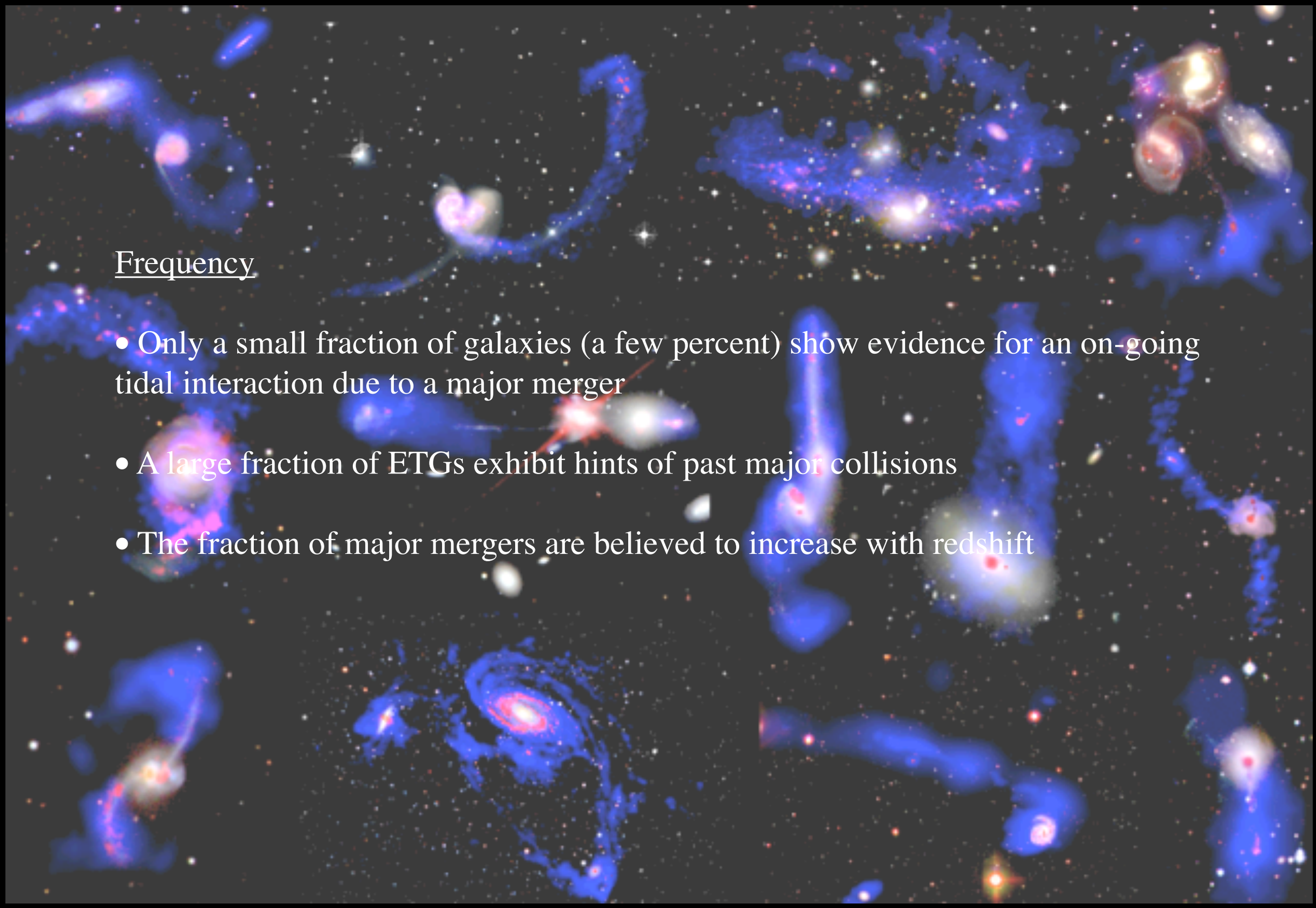


Frequency

- Only a small fraction of galaxies (a few percent) show evidence for an on-going tidal interaction due to a major merger

- A large fraction of ETGs exhibit hints of past major collisions

Mergers in the local Universe



Frequency

- Only a small fraction of galaxies (a few percent) show evidence for an on-going tidal interaction due to a major merger
- A large fraction of ETGs exhibit hints of past major collisions
- The fraction of major mergers are believed to increase with redshift

Mergers in the distant Universe?

Hubble Ultra Deep Field: Beckwitth et al. 2004

Mergers in the distant Universe?

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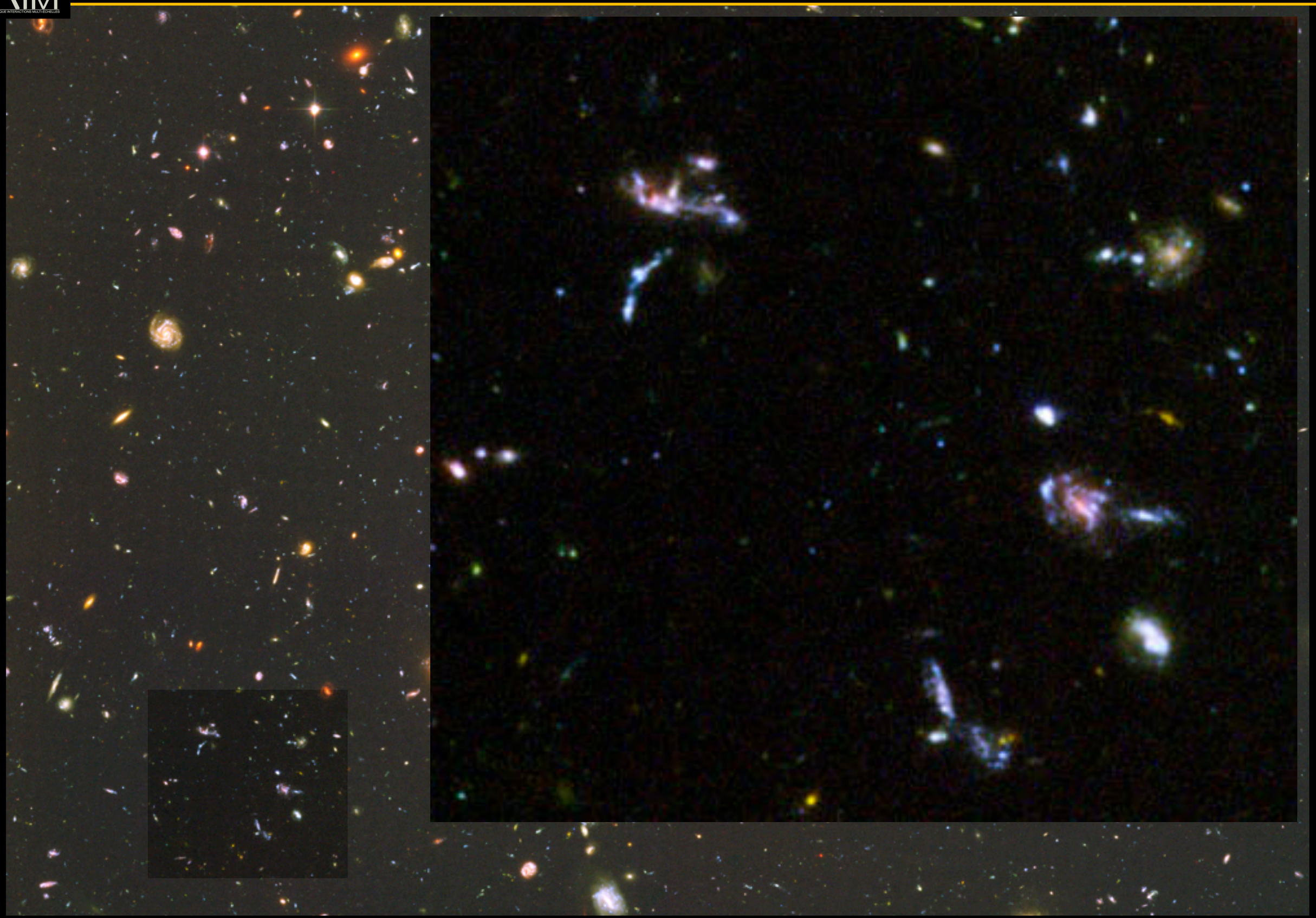
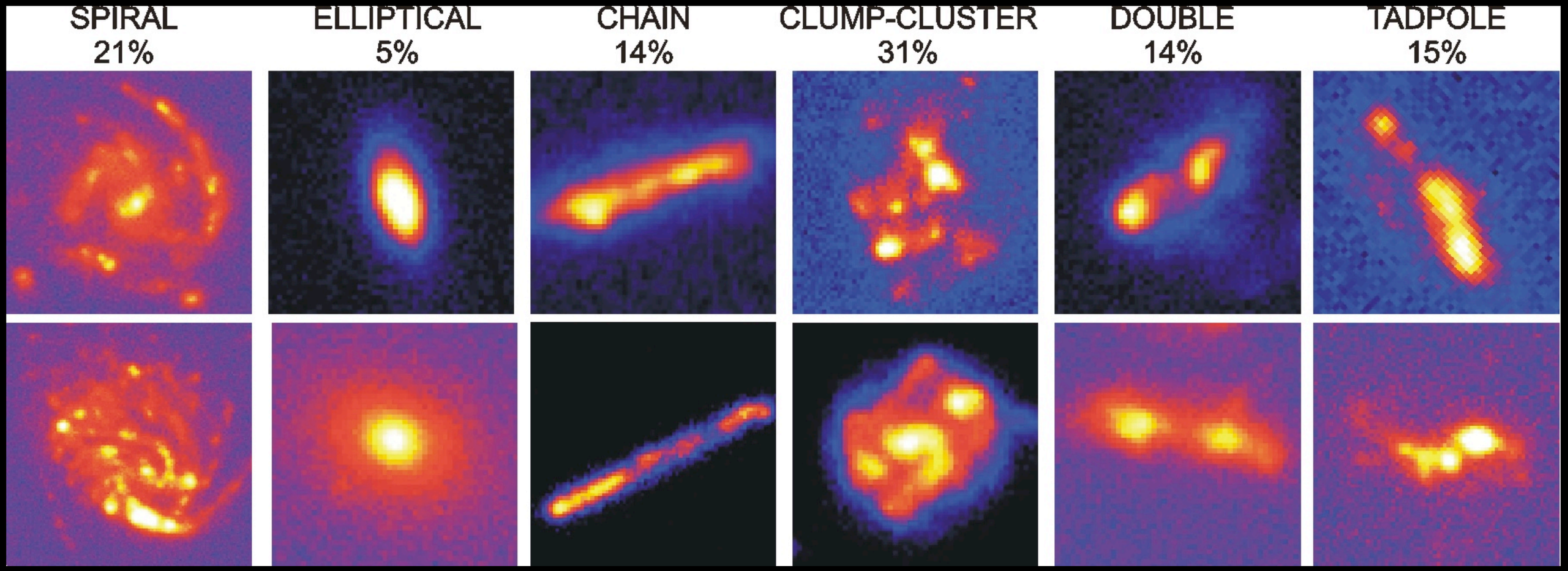


Mergers in the distant Universe?

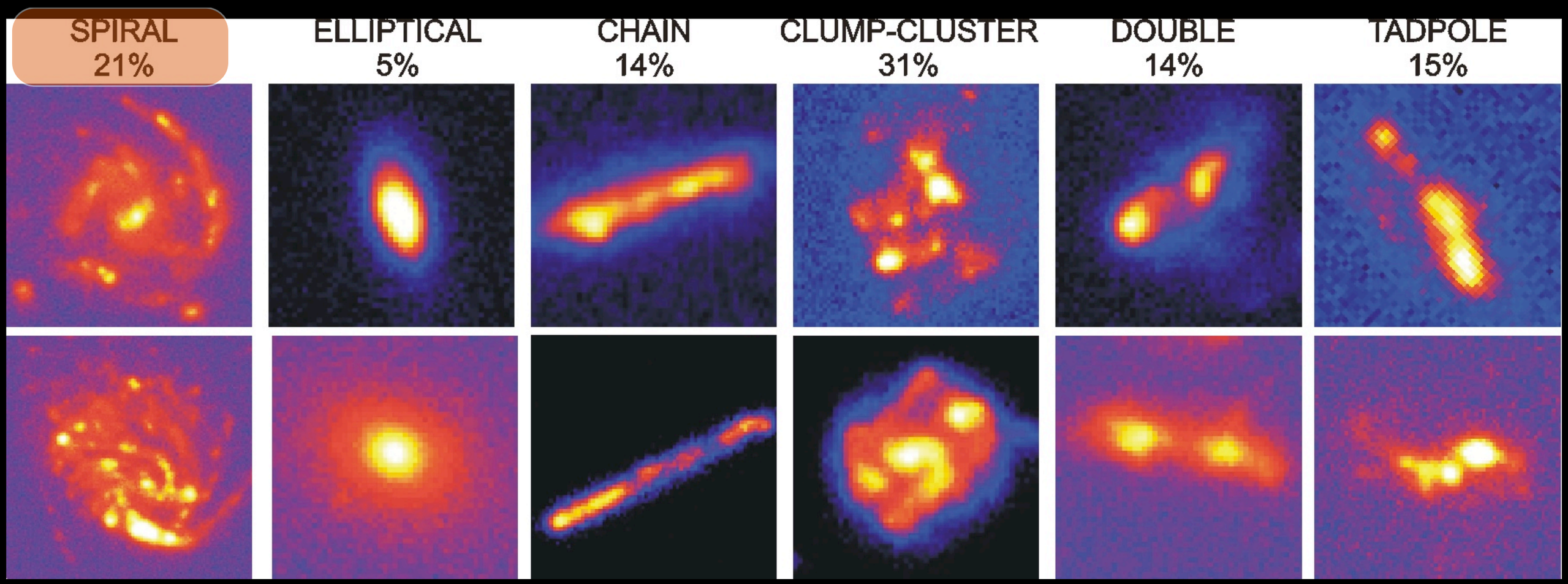
« obvious example of galaxies undergoing some type of merger »

Mergers in the distant Universe?



Local analogues

Mergers in the distant Universe?



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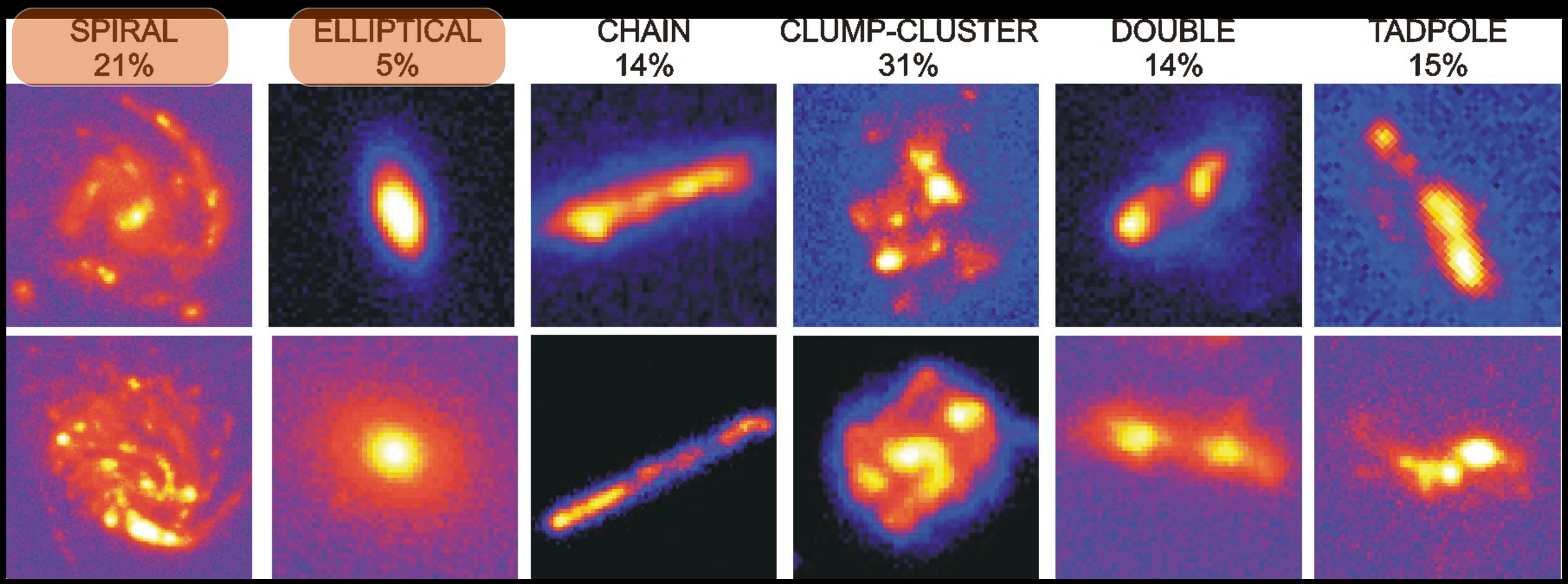

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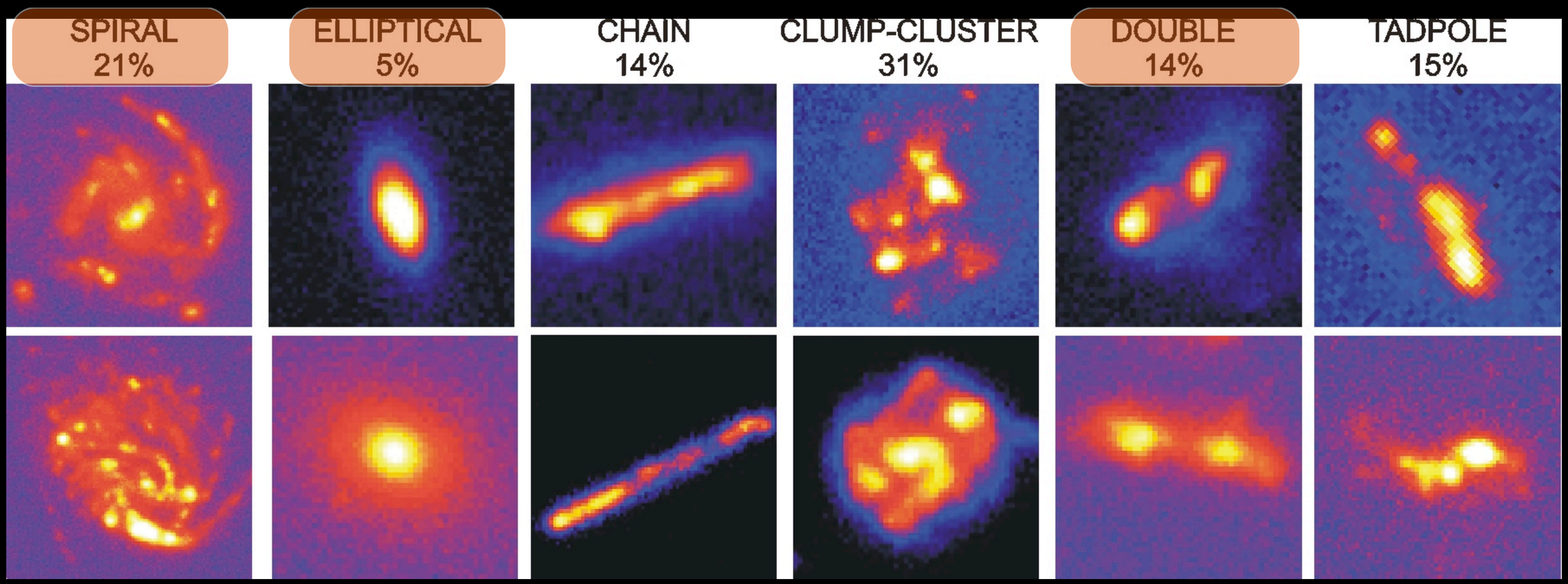

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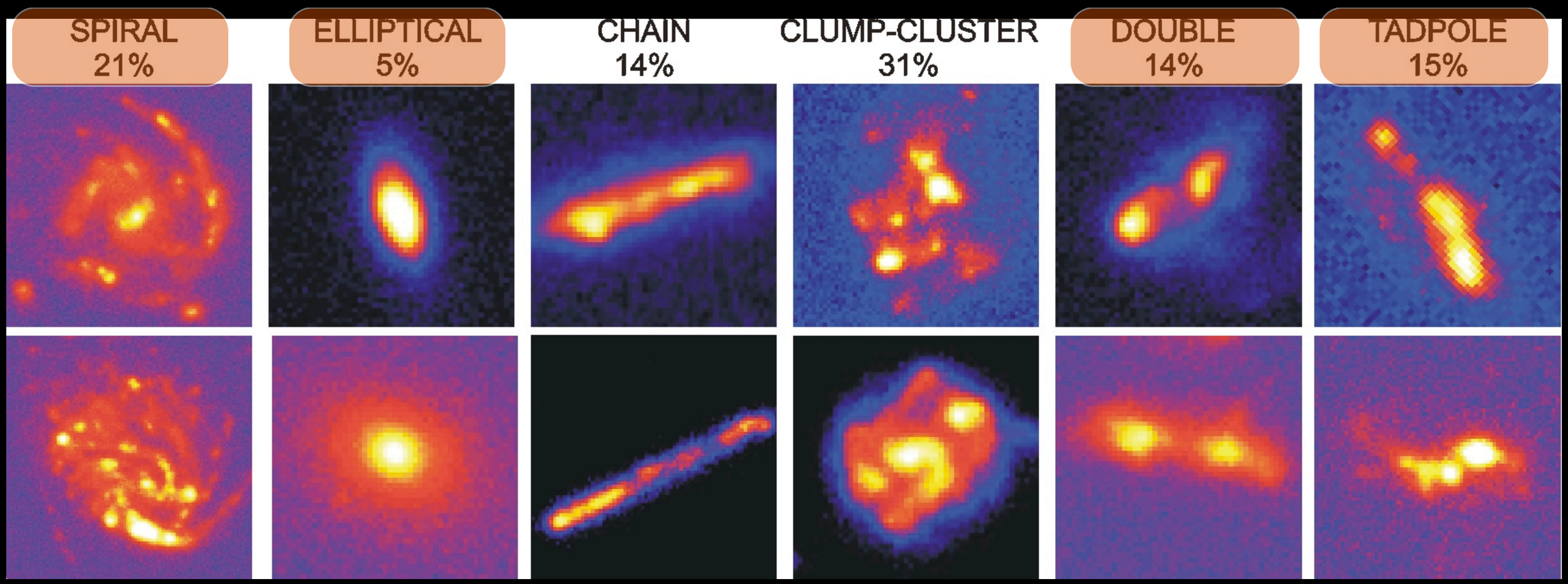

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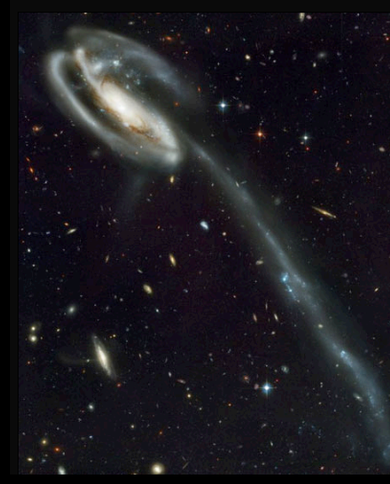

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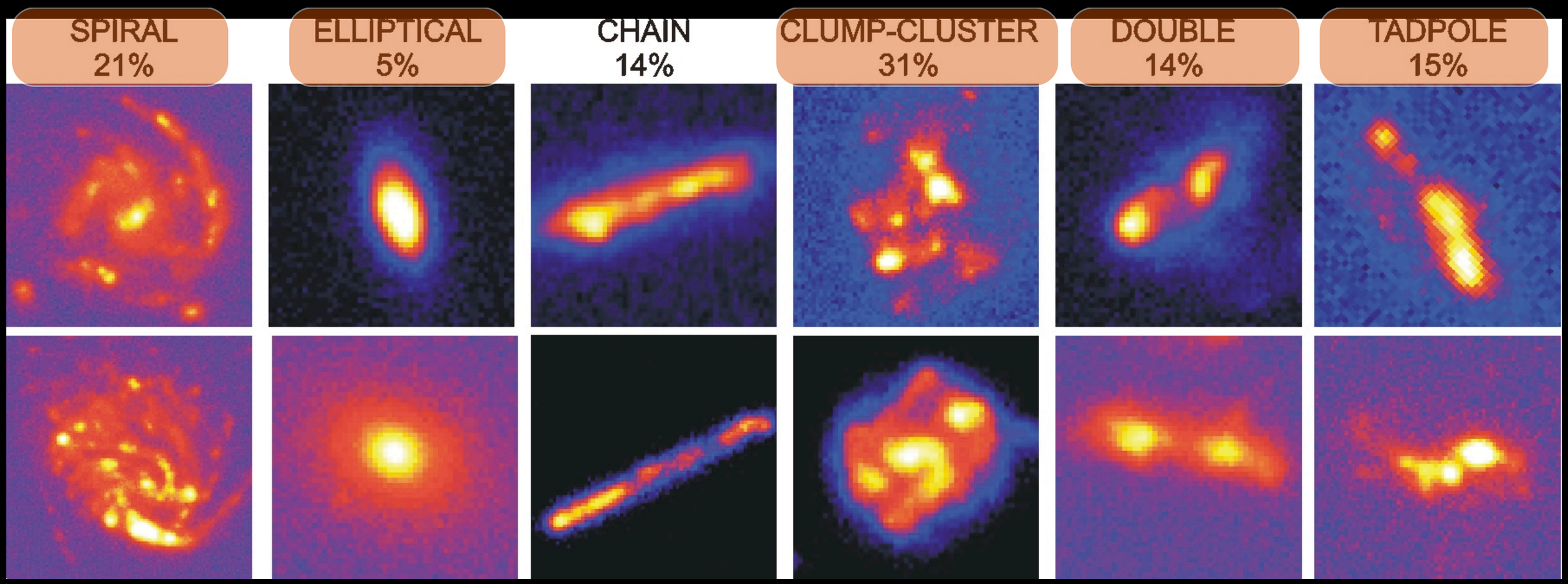

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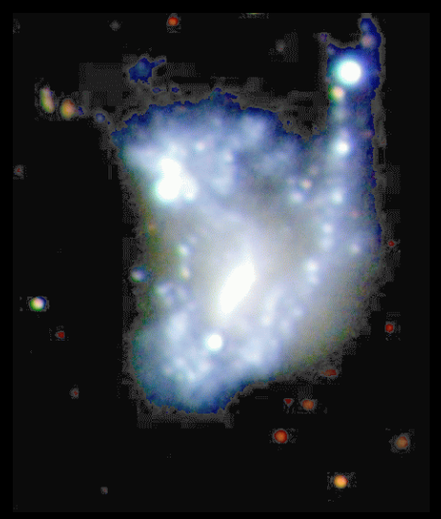
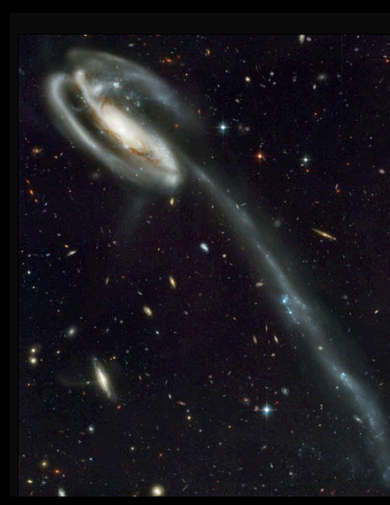
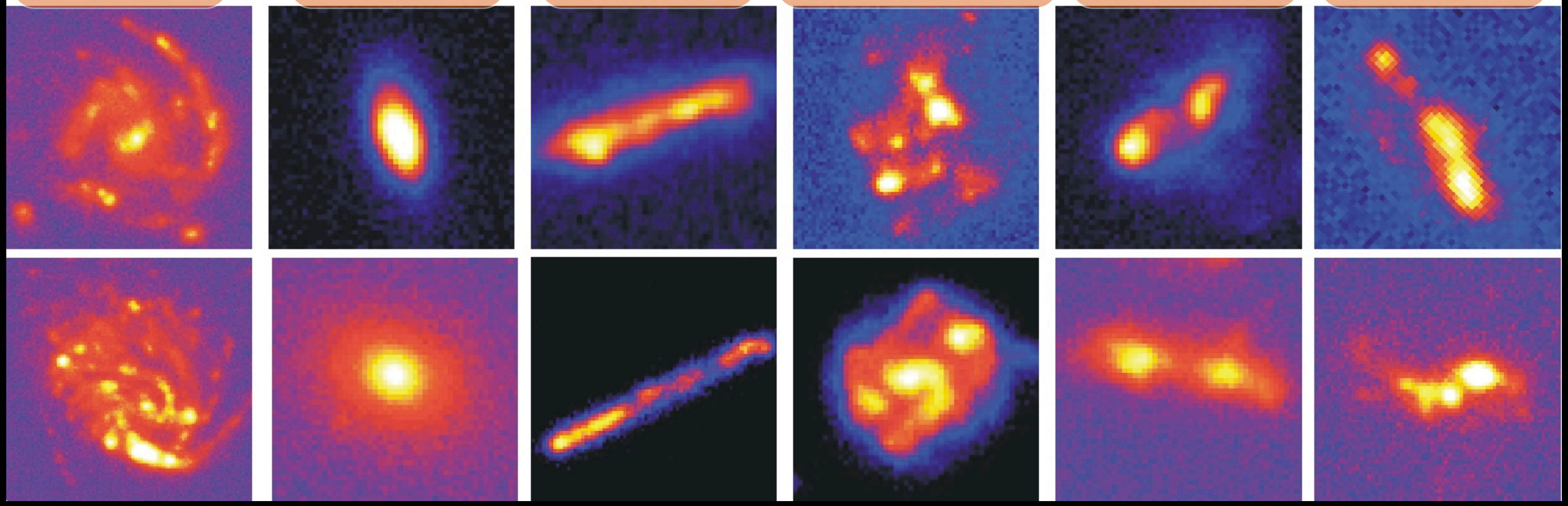
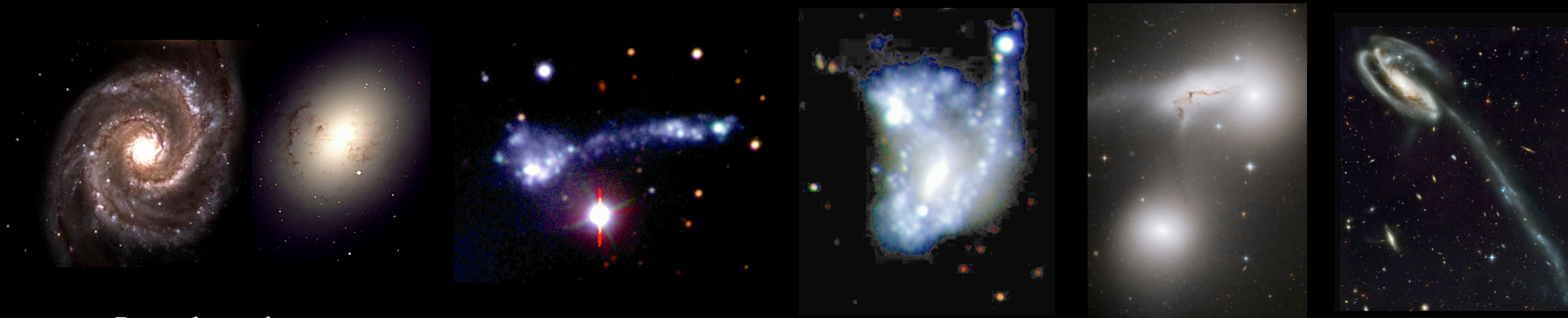




Mergers in the distant Universe?

SPIRAL 21%	ELLIPTICAL 5%	CHAIN 14%	CLUMP-CLUSTER 31%	DOUBLE 14%	TADPOLE 15%





Local analogues

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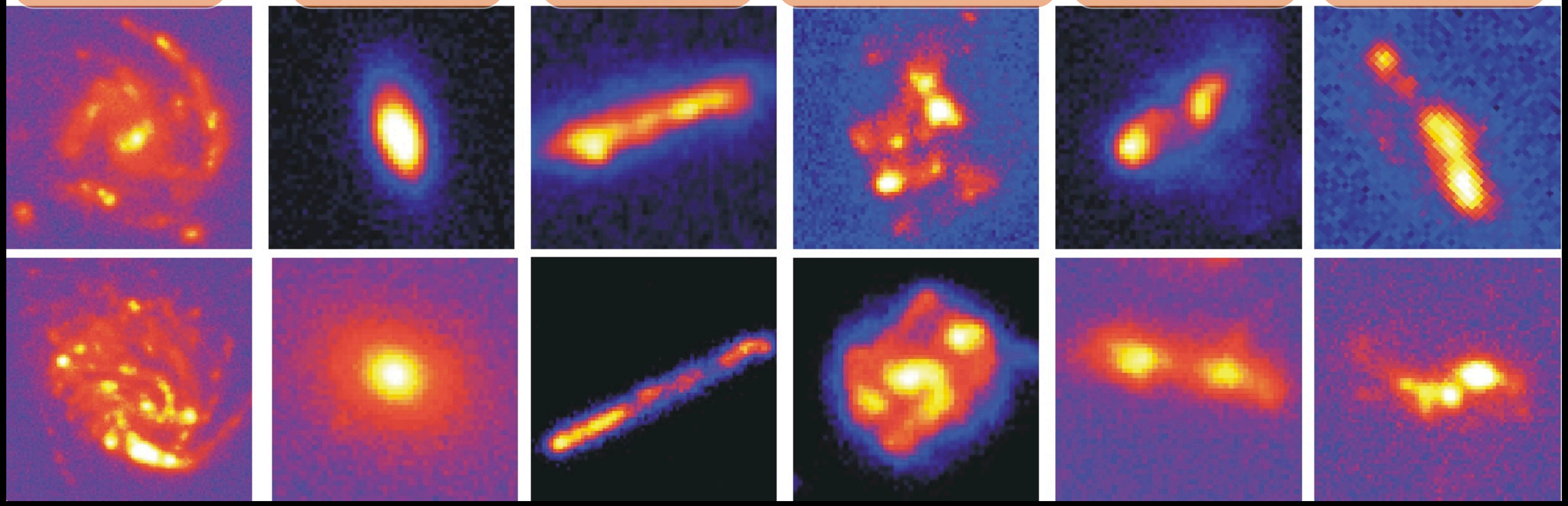
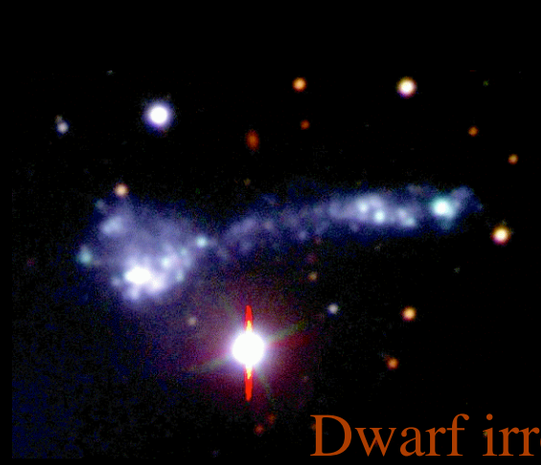


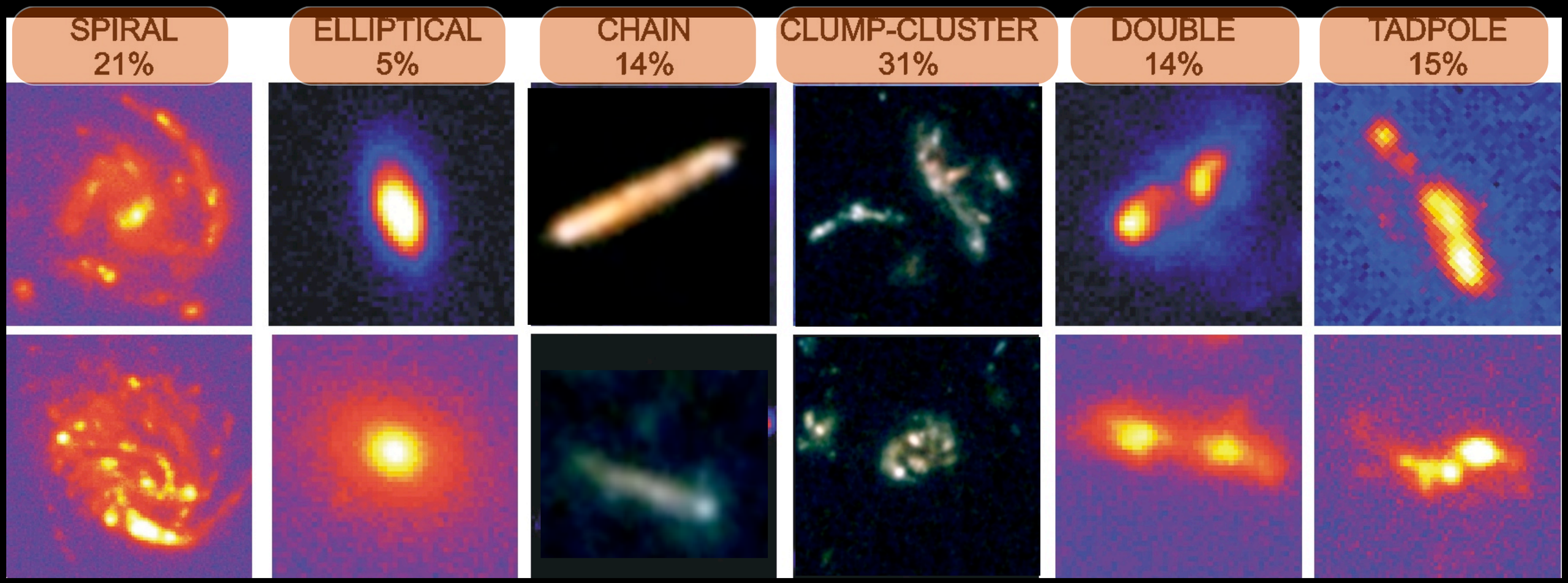


Dwarf irregular galaxies!

Local analogues

Mergers in the distant Universe?

Elmegreen et al. 2007



Local analogues

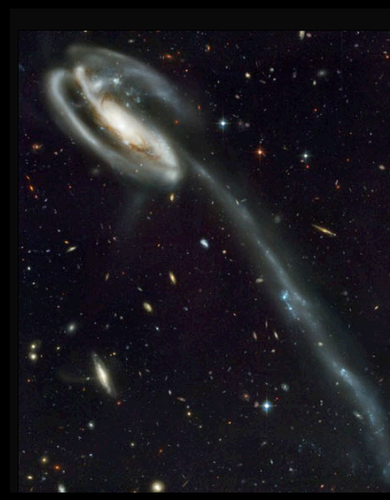
Star-Forming clumps:

- 1000 times more massive:

10^8-10^9 M_O

- Ages of the clumps ~100-500 Myr

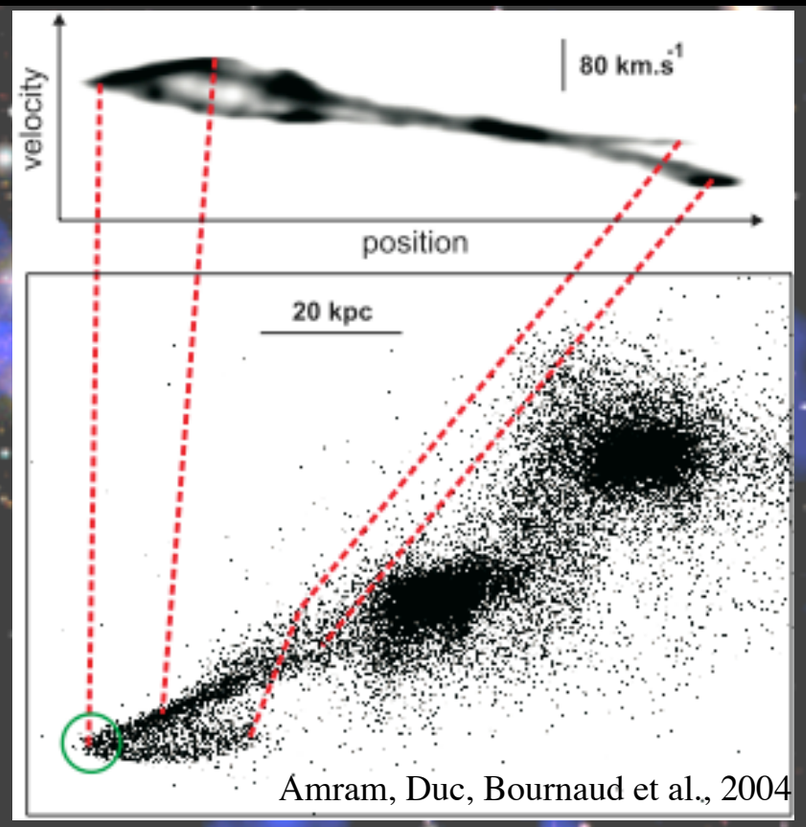
Are they really merging nuclei?



Kinematical signature of mergers: z=0 and simulations

✓Streaming motions along tidal tails,with velocity gradient larger than the circular velocity of the parent galaxies

✓Weird projection effects



Amram, Duc, Bournaud et al., 2004

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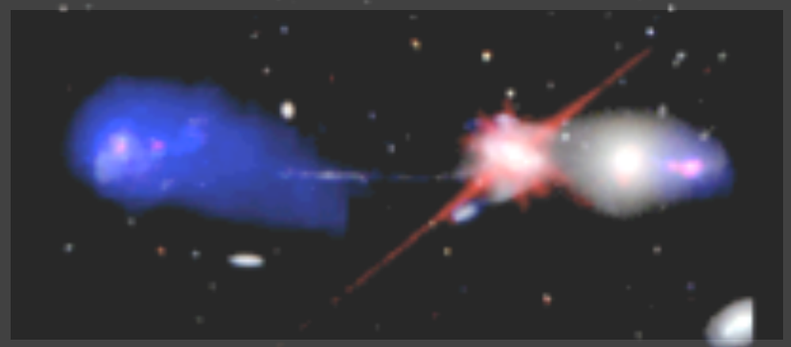

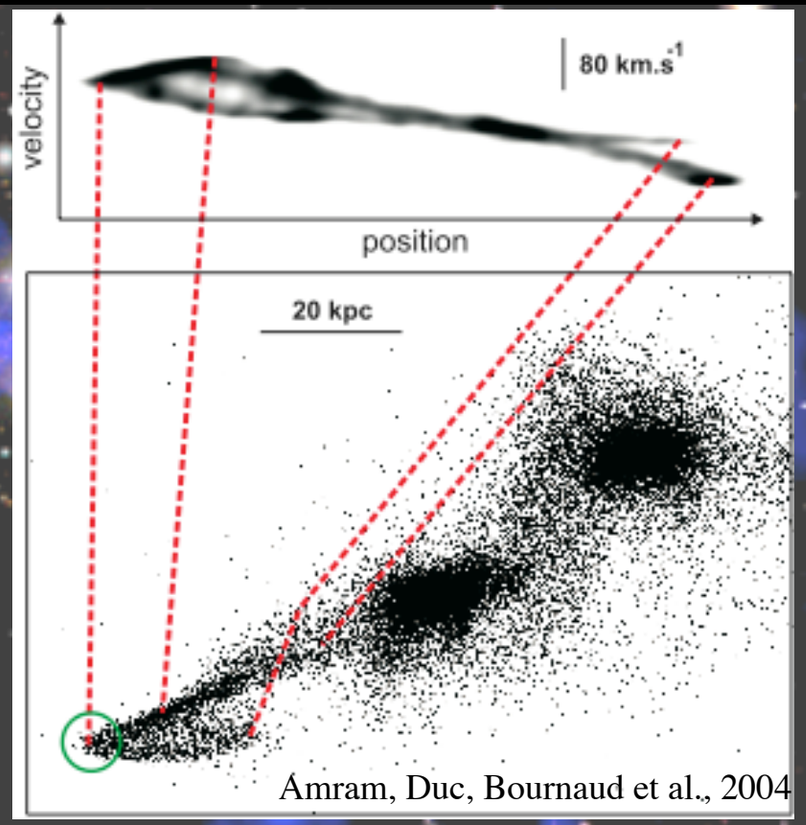

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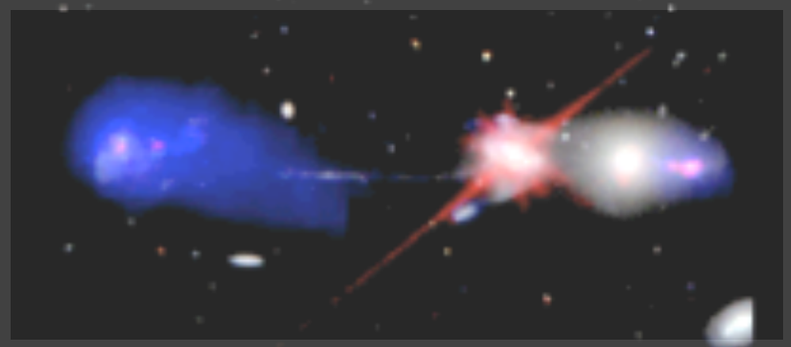

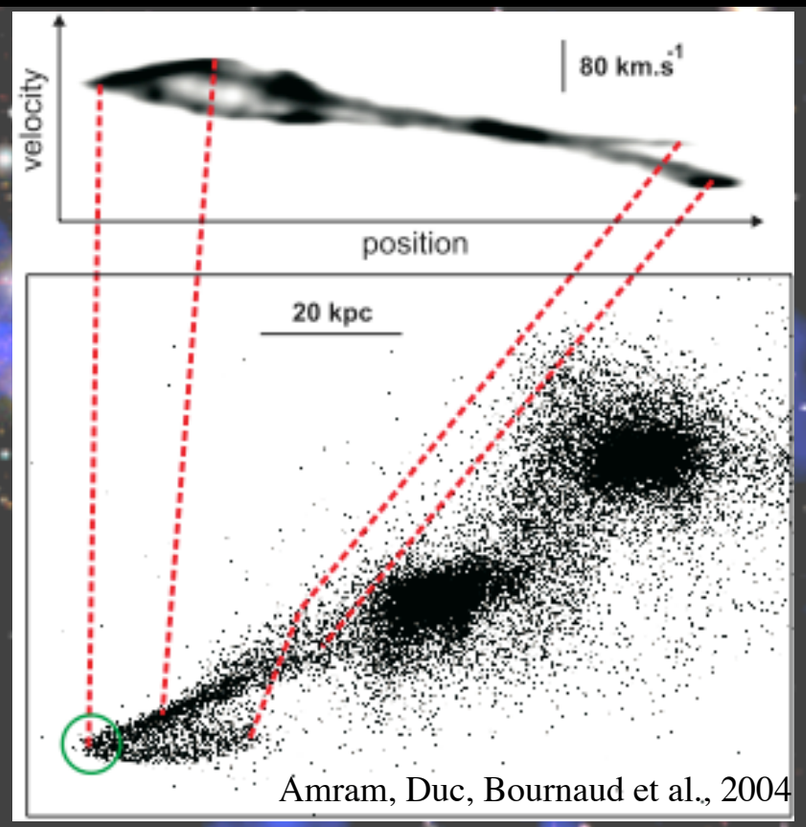

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Arp 105

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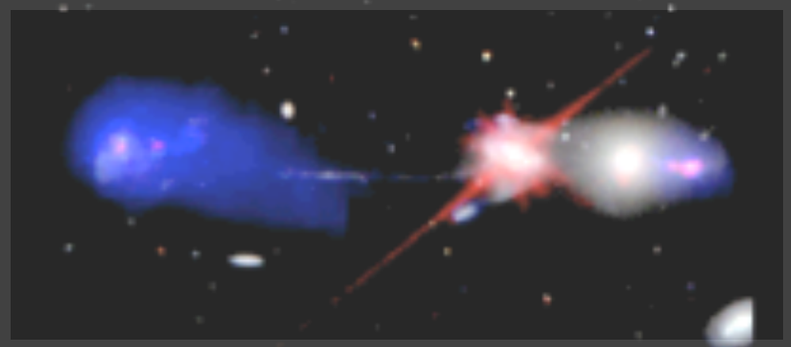

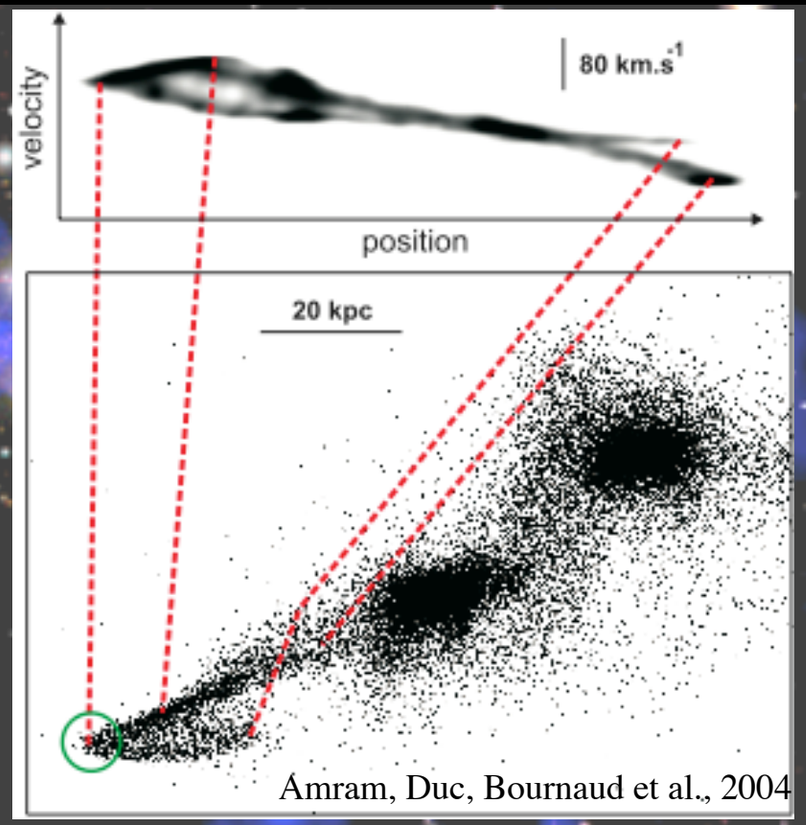

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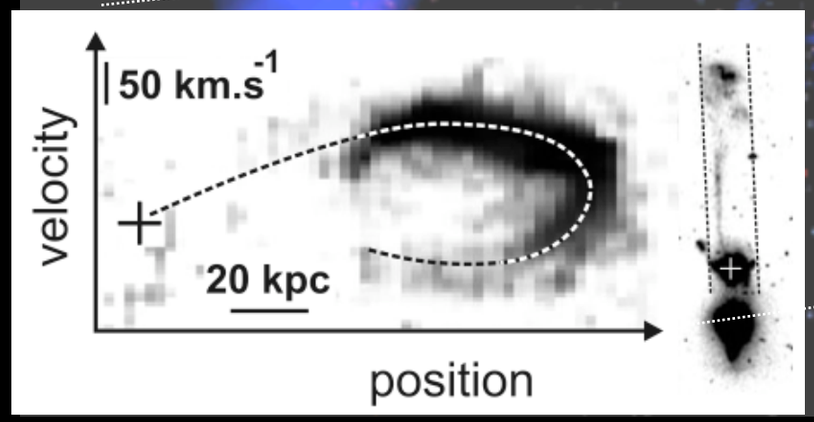

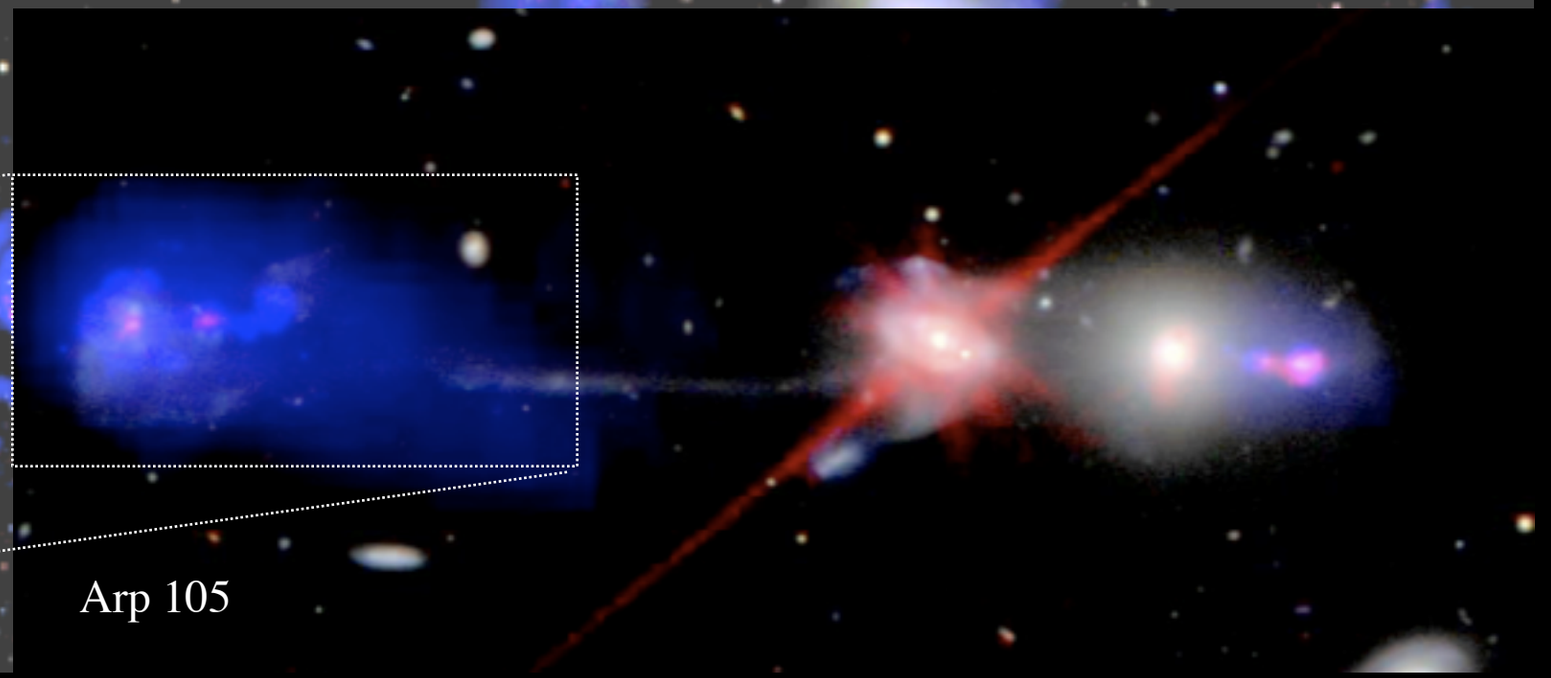

Arp 105

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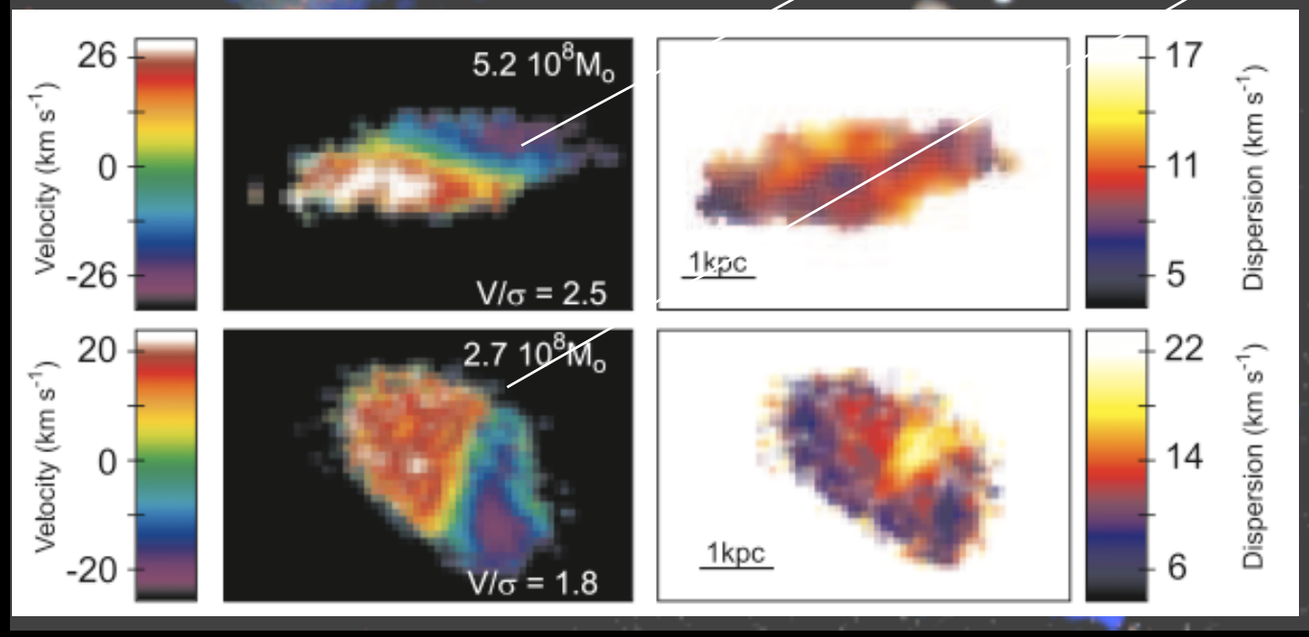
✓KDCs + decoupled components in tidal debris



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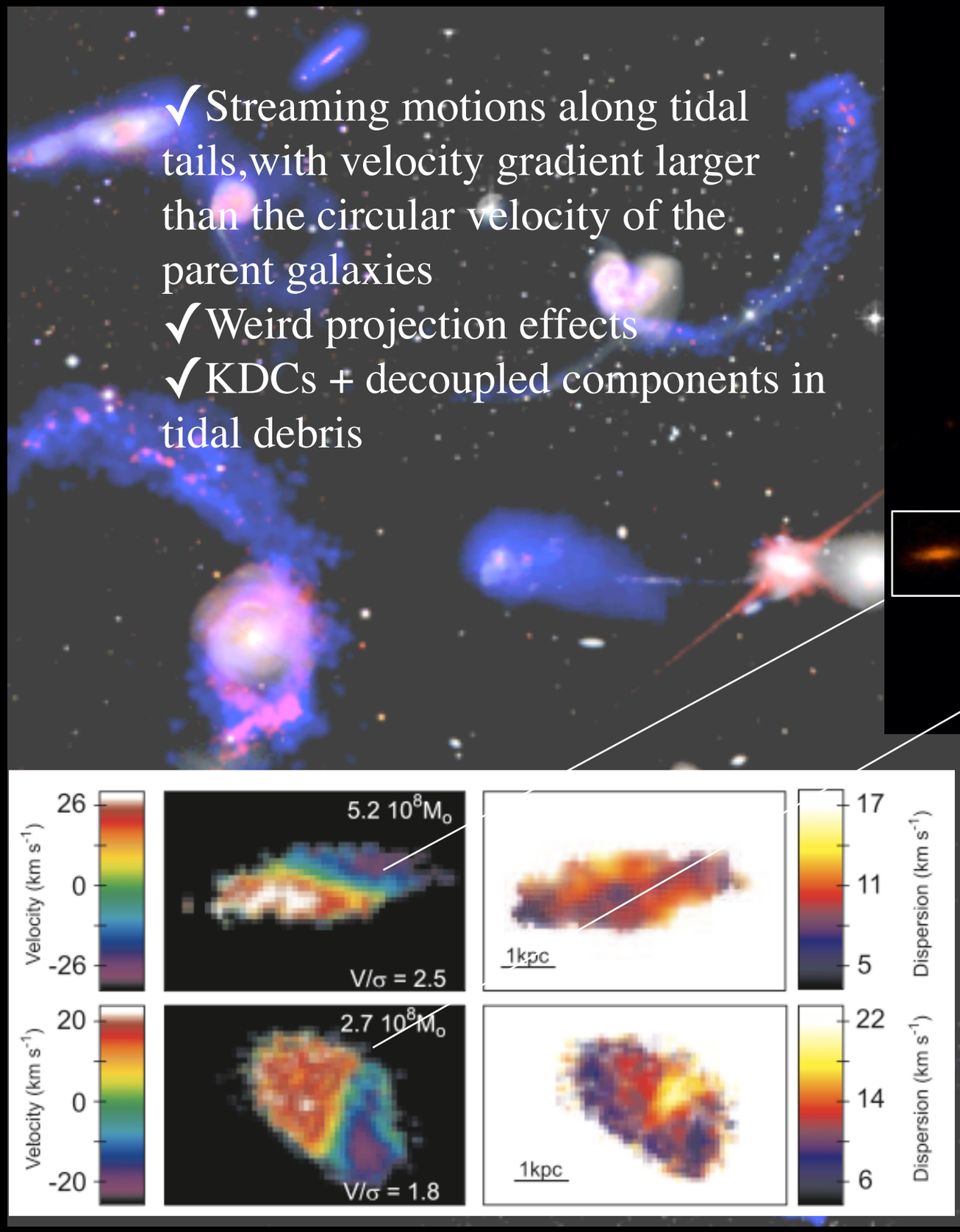
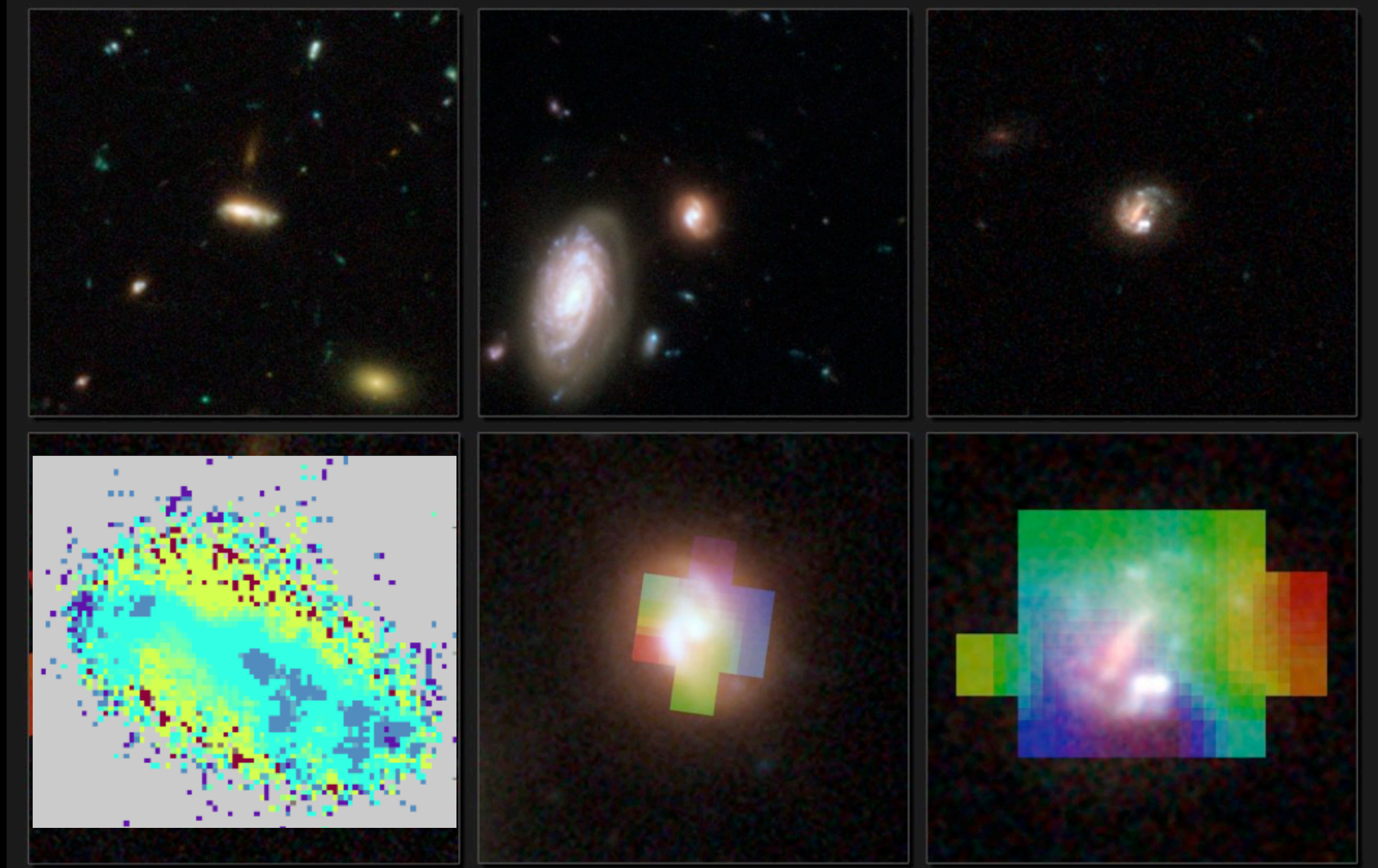


Kinematical signature of a merger: a mess ... unlike rotating disk!

Kinematical signature of mergers?: z=0.6

Puech et al., 2009; Hammer et al., 2009

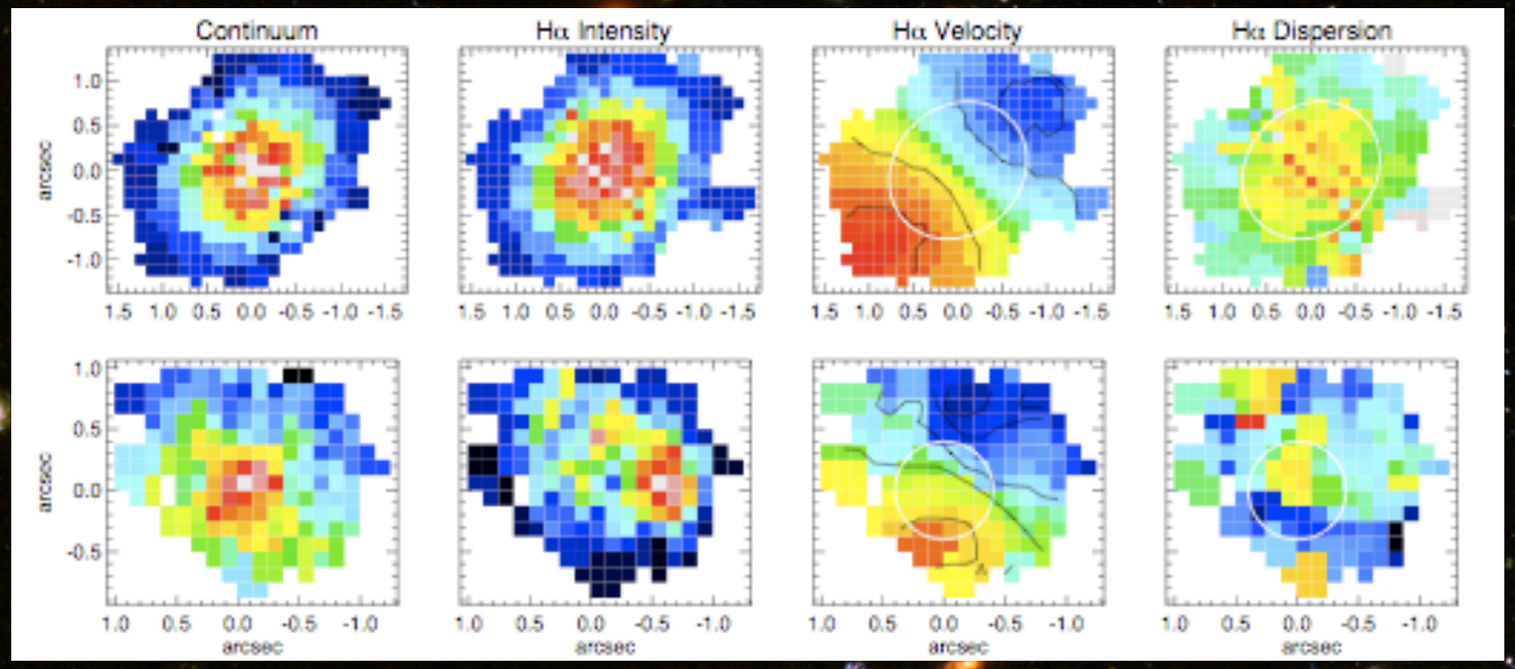
Kinematical signature of mergers?: z=0.6



Puech et al., 2009; Hammer et al., 2009

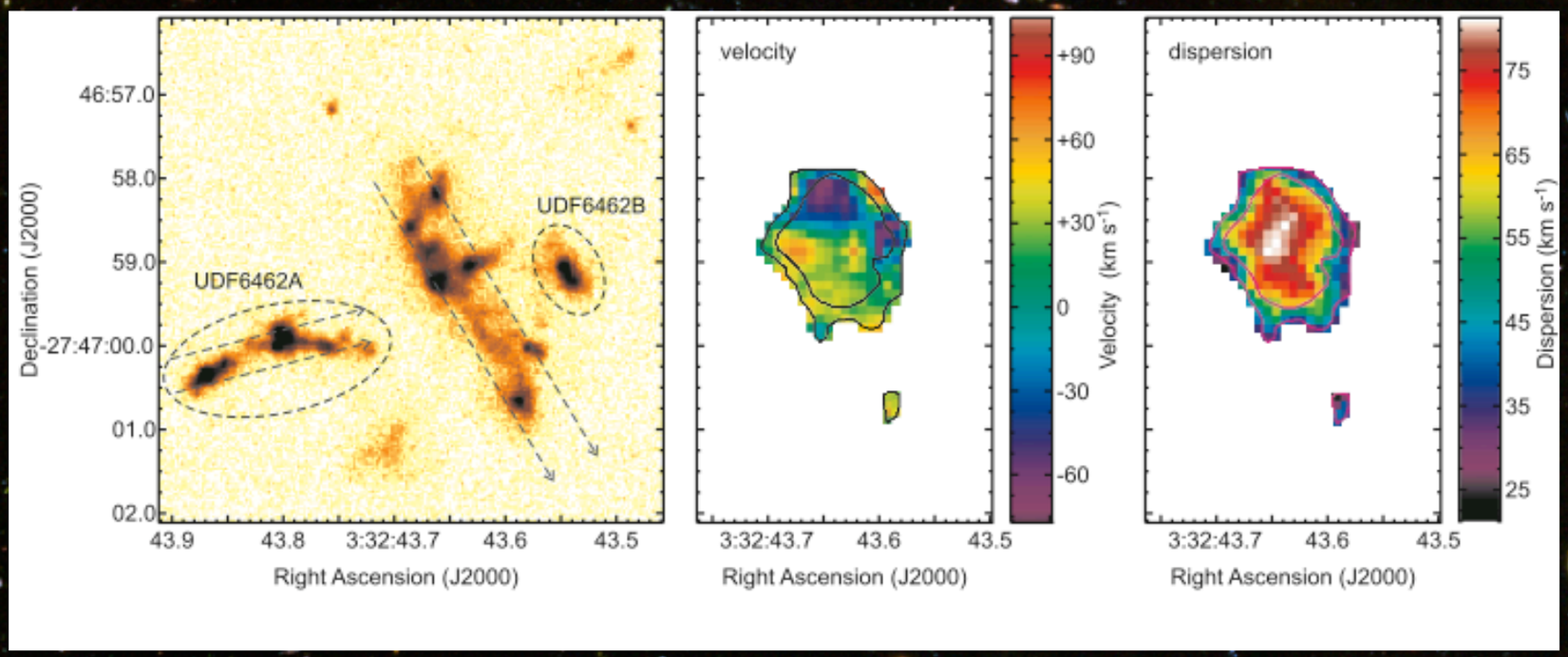
The peak of velocity dispersion is displaced!

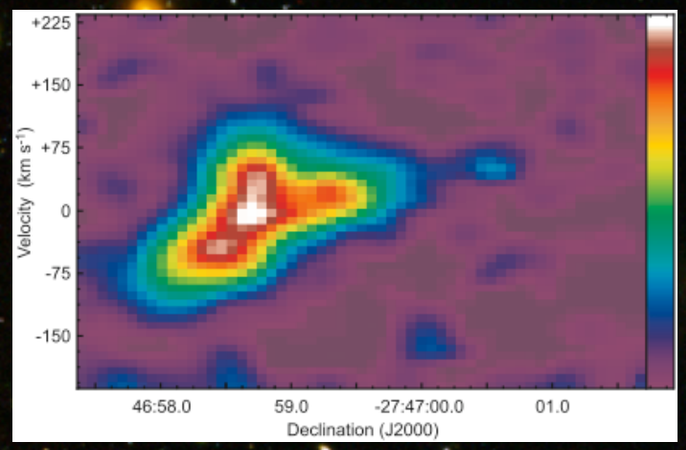
Kinematical signature of mergers?: z=1.5-2



kinemetry of high redshift galaxies
Shapiro et al. 2008

kinematics of ionized gaz in clumpy galaxies with VLT/SINFONI





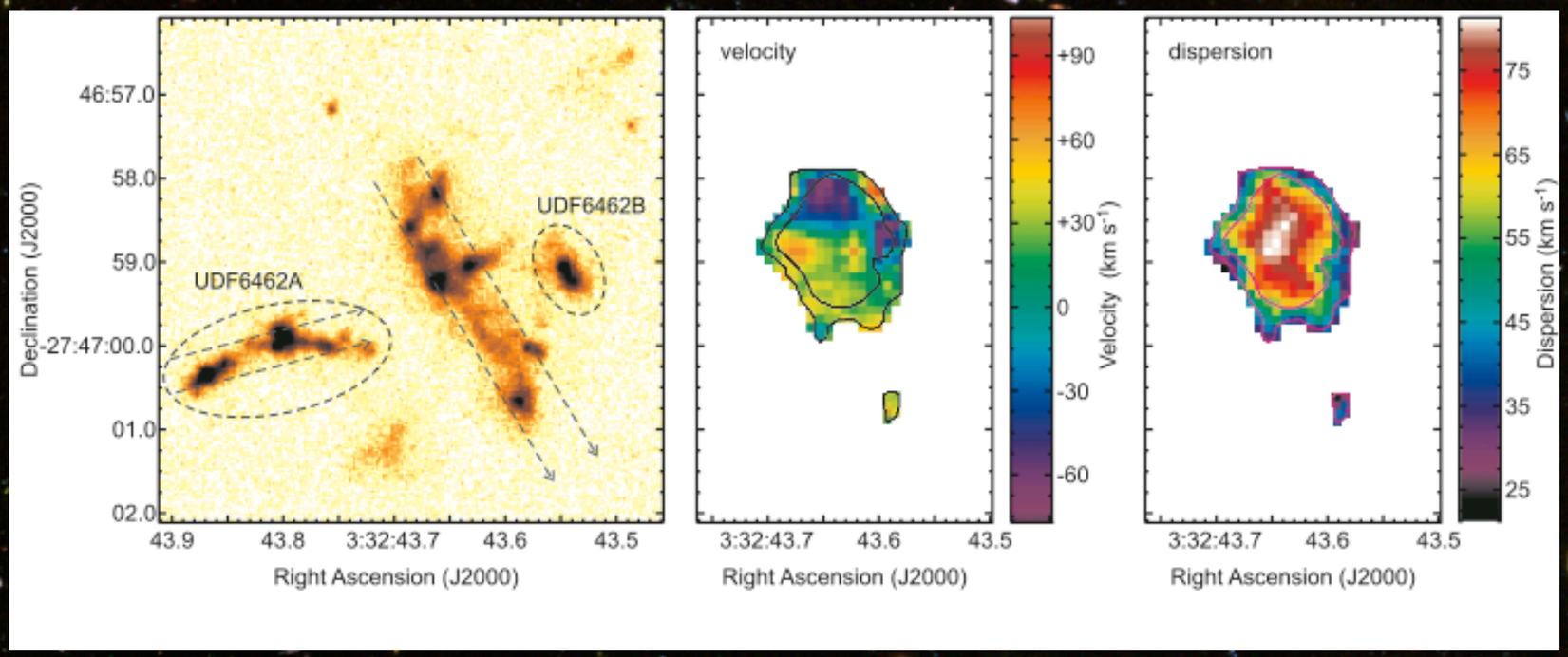
- Global rotation
- Central -peak
- Individual clump velocities can differ by 50 km/s

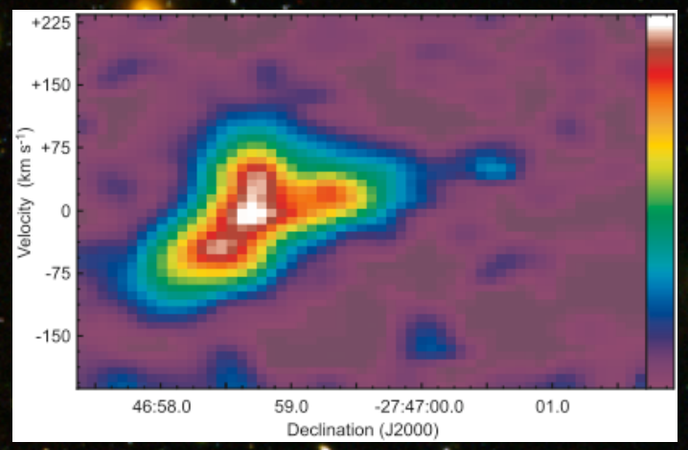
Bournaud, Daddi, Elmegreen et al. 2008

Kinematical signature of mergers?: z=1.5-2

• The internal kinematics of clumpy galaxies is consistent with that of a rotating disk with local condensations

kinematics of clumpy galaxies with VLT/SINFONI





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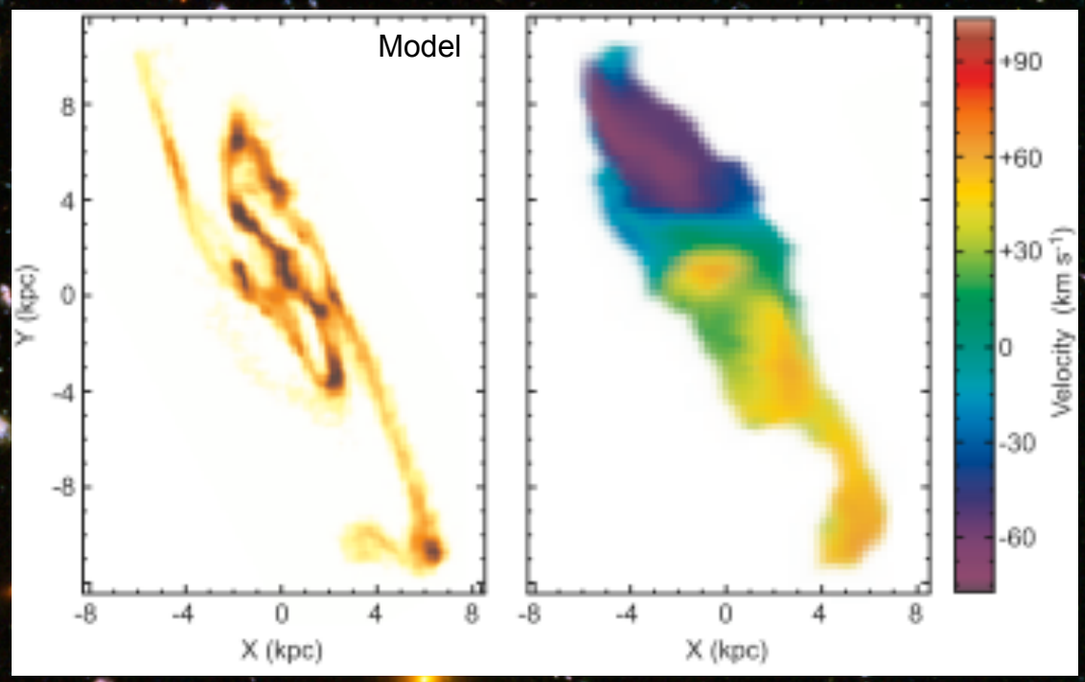
Bournaud, Daddi, Elmegreen et al. 2008

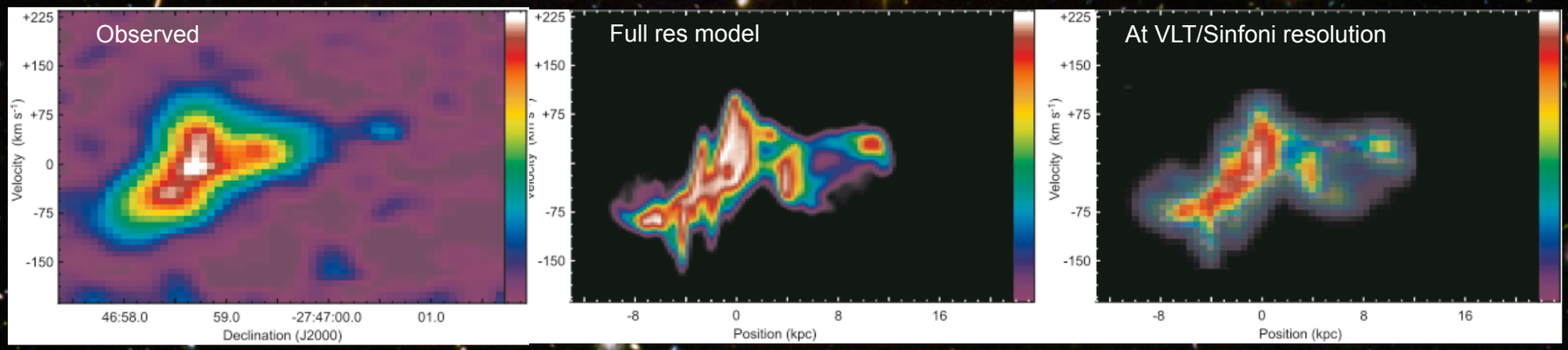
Numerical model of clumpy galaxies

Model



Bournaud et al. 2008

PV-diagrams



A model with internal clump formation able to reproduce the morphology (non-exponential disk) and (perturbed) kinematics of the system

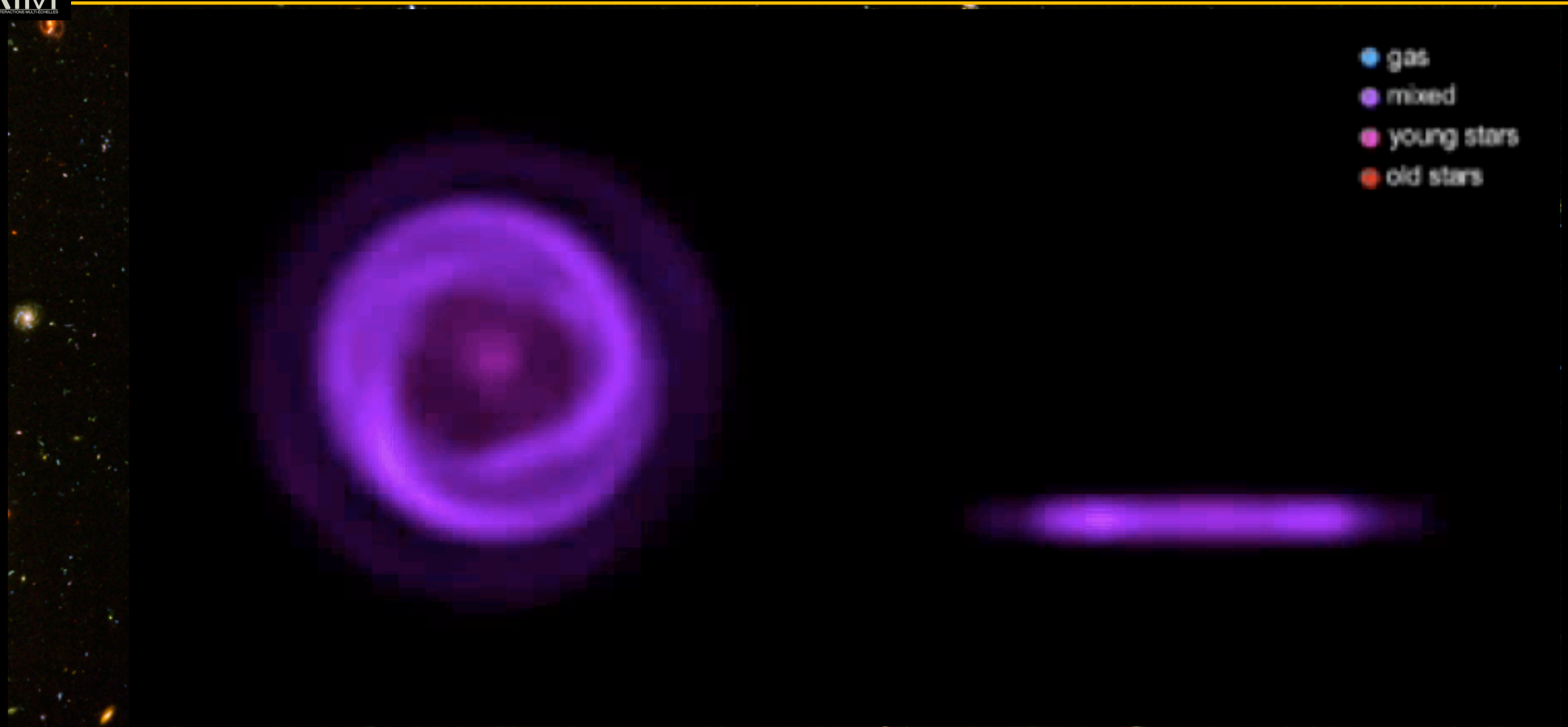
Numerical model of clumpy galaxies

Bournaud, et al. 2007

Initial setup of the simulations:
- non-exponential disk
- high gas fraction (50% stars, 50% gas), no bulge
- dark matter halo

Resolution of 100 pc, 1 million particles

Numerical model of clumpy galaxies



Bournaud, et al. 2007

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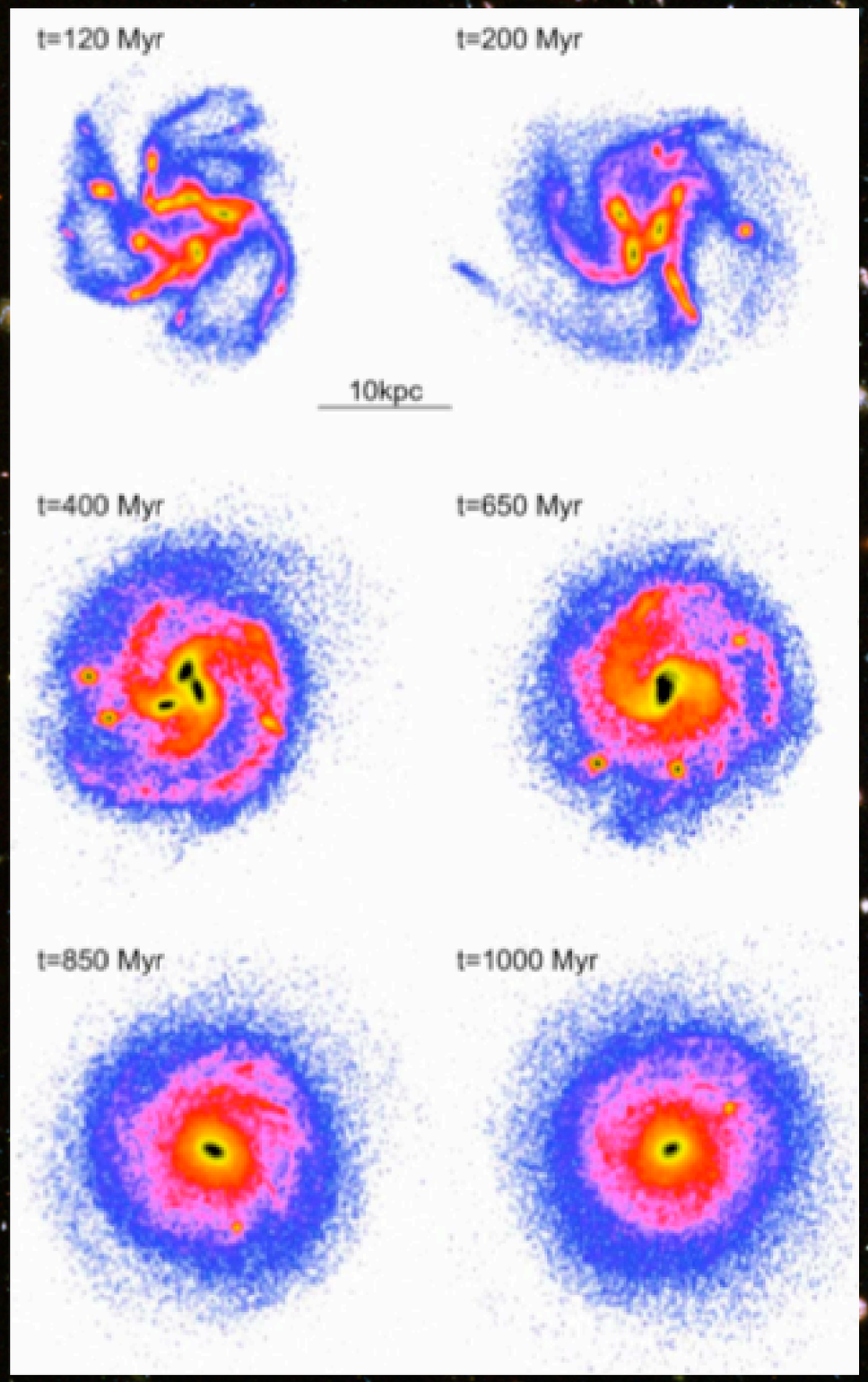
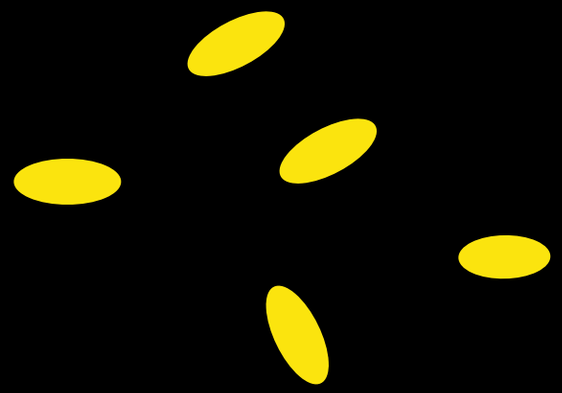


- Disk in instable (Q< 1)
- Massive clumps are formed, containing 50% of disk mass
- The clumps interact and migrate to the center, while losing some mass
- A bulge is formed (bulge/disk of about 0.3, with low V/σ)

Mergers vs internally-clumpy disks?



Merger scenario

✓ Initially separate galaxies formed in separate halos merge

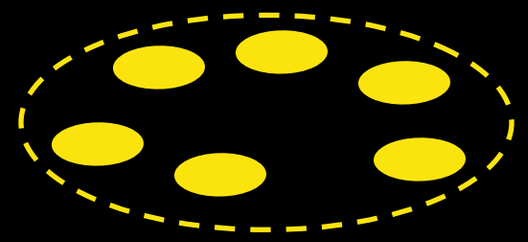
Disk fragmentation scenario

✓Clumps made within a single halo merge

- Gravitationnal instabilities internal to a single halo
- High turbulent gas (σ of 50 km/s) form massive clumps

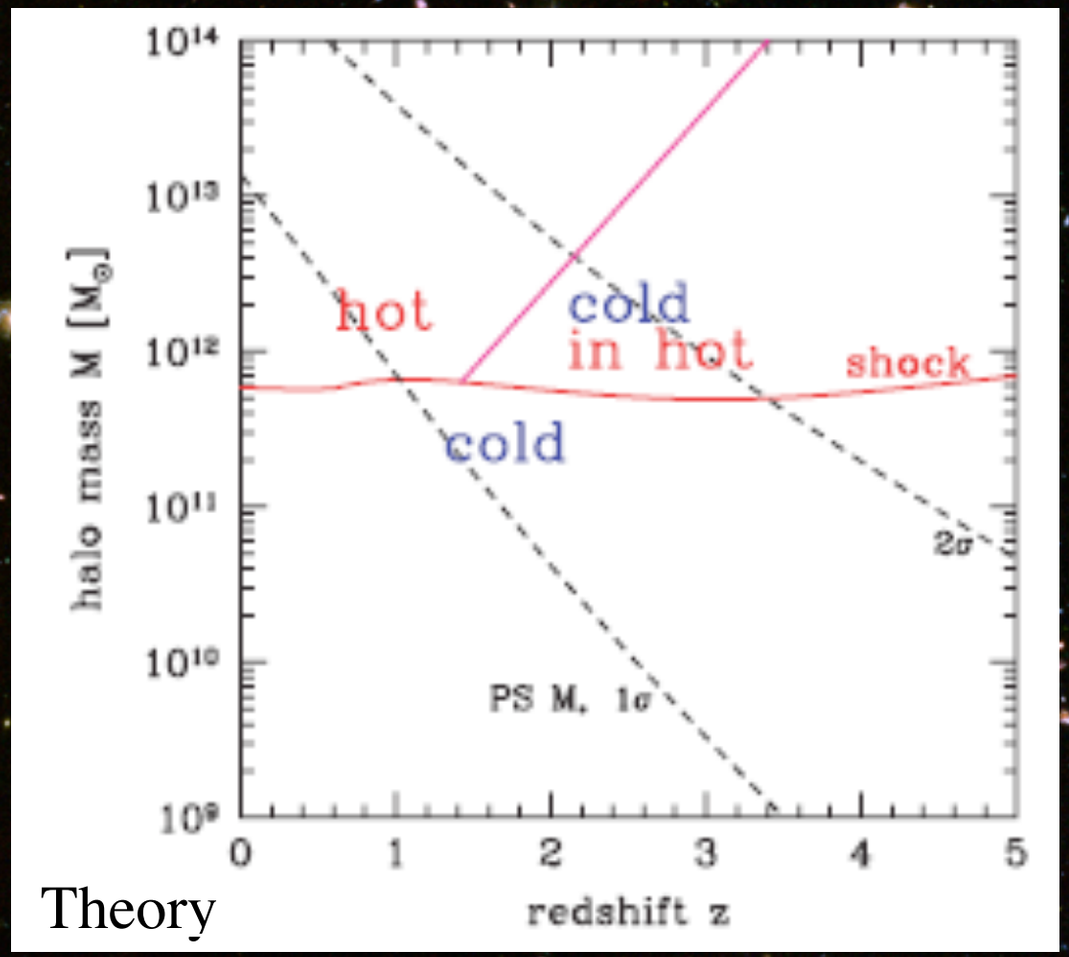
(at Jeans mass 10^9 Mo) which may collapse (Q prop to σ k/Σ<1) if the gas+stars column density is high in disk

- Spheroids prevent the formation of SF clumps

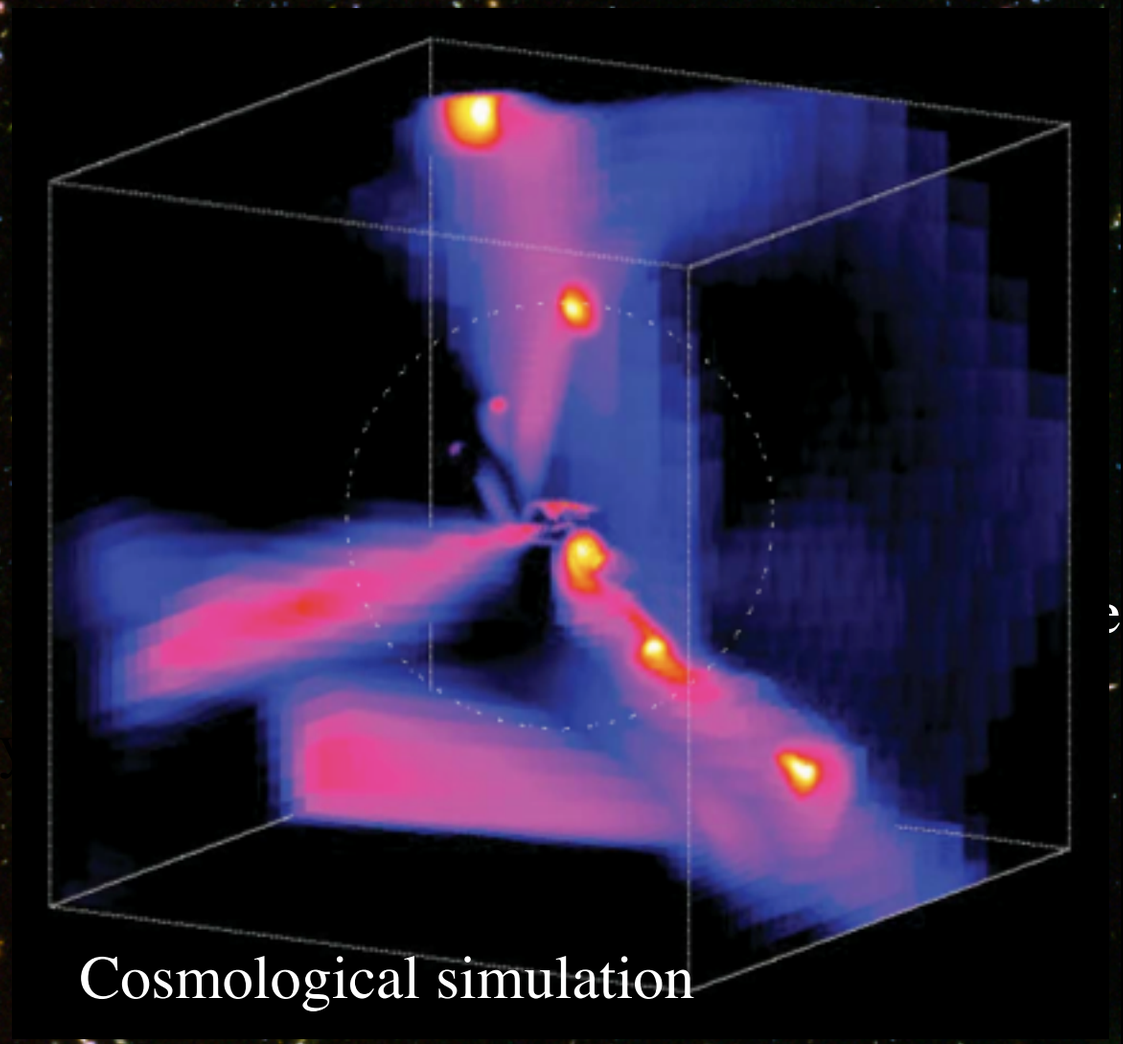


- This scenario implies the smooth accretion of baryons (i.e. not via mergers) to avoid the formation of bulges

Theoretical evidence for important cold accretion at high-z



Dekel & Birnboim 2006



Dekel et al., 2009

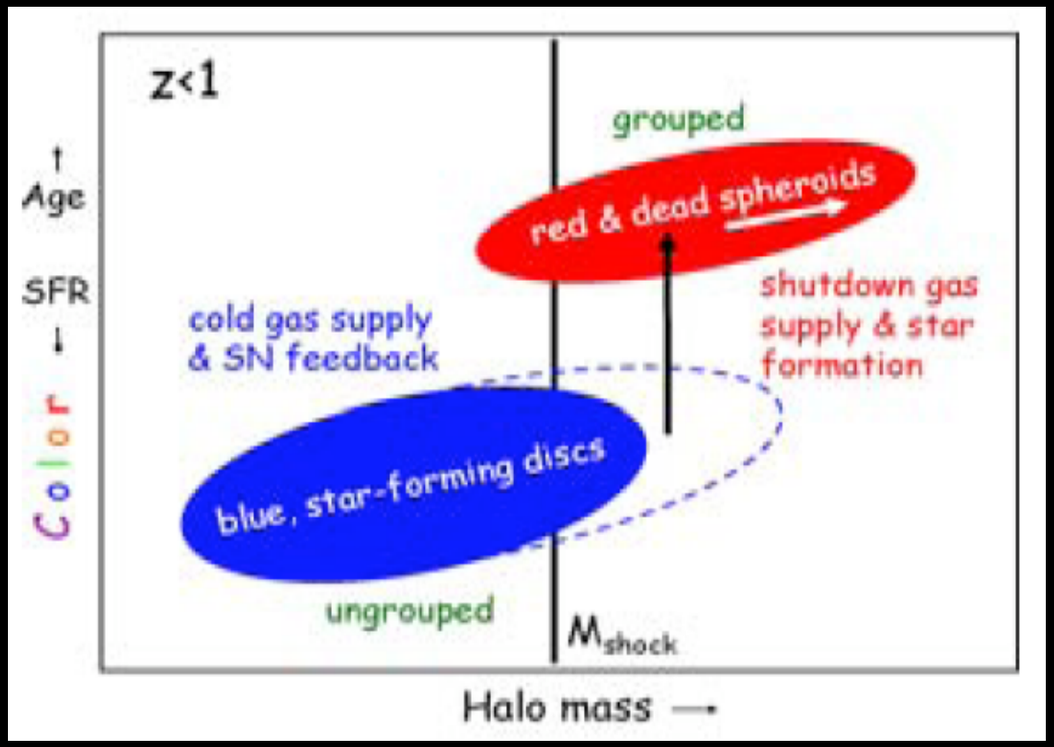
- Above a critical halo mass, accreted gas is shocked and no longer fuel disks
- However, at high z, accretion may still occur through dense filaments of cold gas

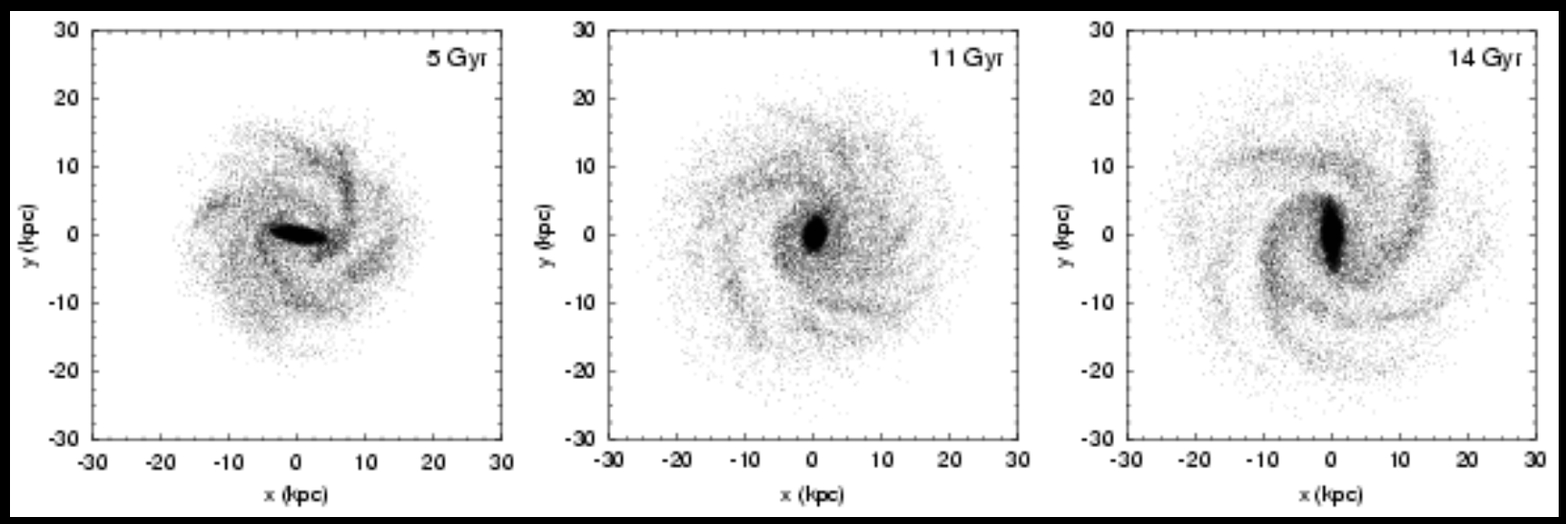
Efficient way to collect large quantities of gas within the disk

Indirect observation evidence of moderate cold accretion at low-z

- At low-z, most of the accretion is prohibited by the halos: morphological evolution driven by mergers (formation of red sequence?)

- Moderate cold accretion may however explain some properties of spirals: lopesideness and bar frequency



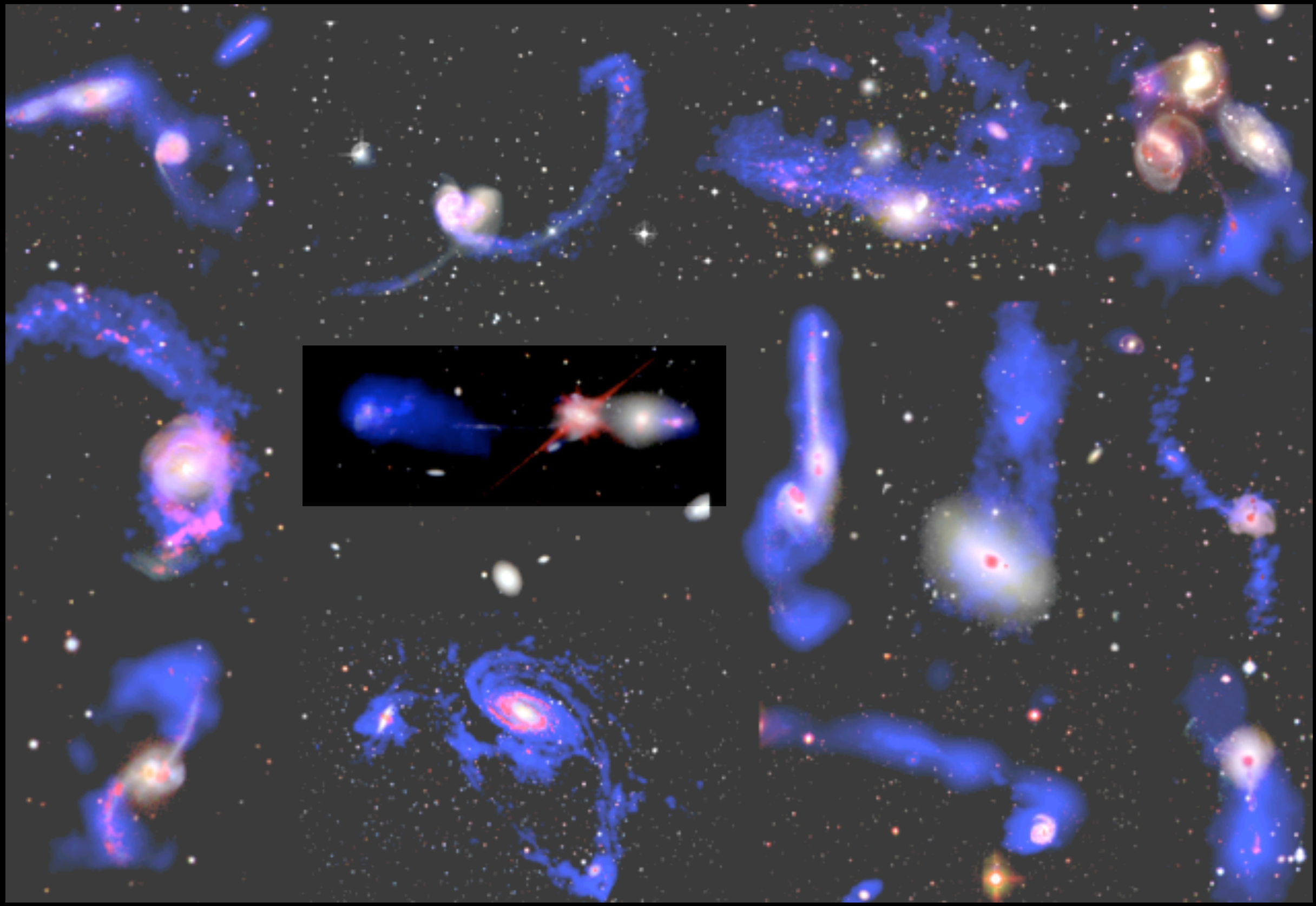


Resurection of bars by gas accretion

Lopesided galaxy

Star formation in low-z mergers

Star formation in low-z mergers



Star formation in low-z mergers

Star formation in low-z mergers

Boquien et al., 2007,09

Star formation in low-z mergers

Boquien et al., 2007,09

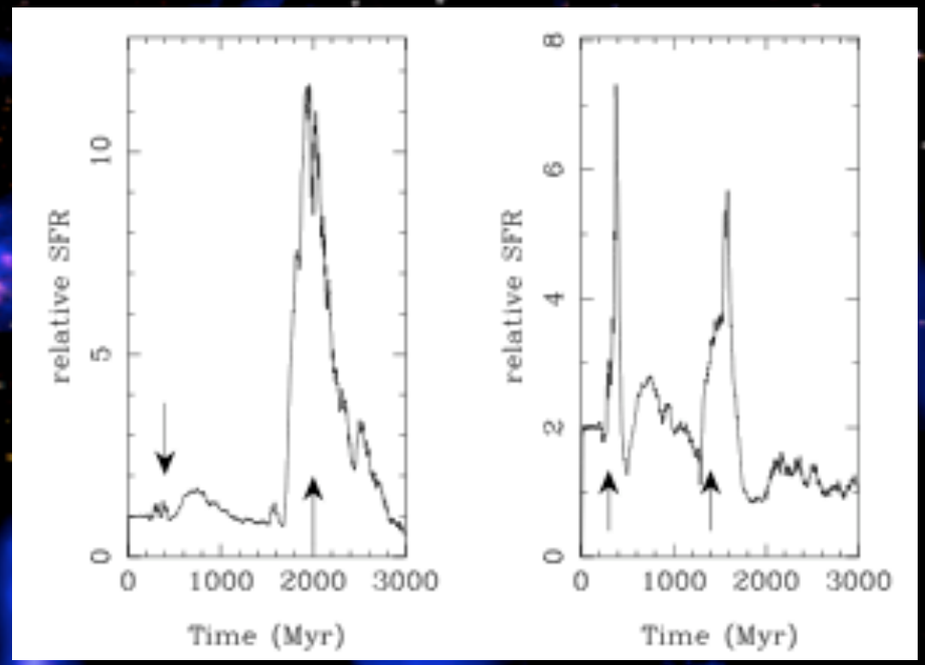
Central nuclear burst + Extended Star Formation

Star formation in low-z mergers

- Paired galaxies have statistically a higher SFR than isolated galaxies

- Numerical simulations predict a SFR enhancement: SFR increased by a factor greater than 5 are rare and found only in about 15% of major galaxy interactions and mergers (Di Matteo et al., 2009)

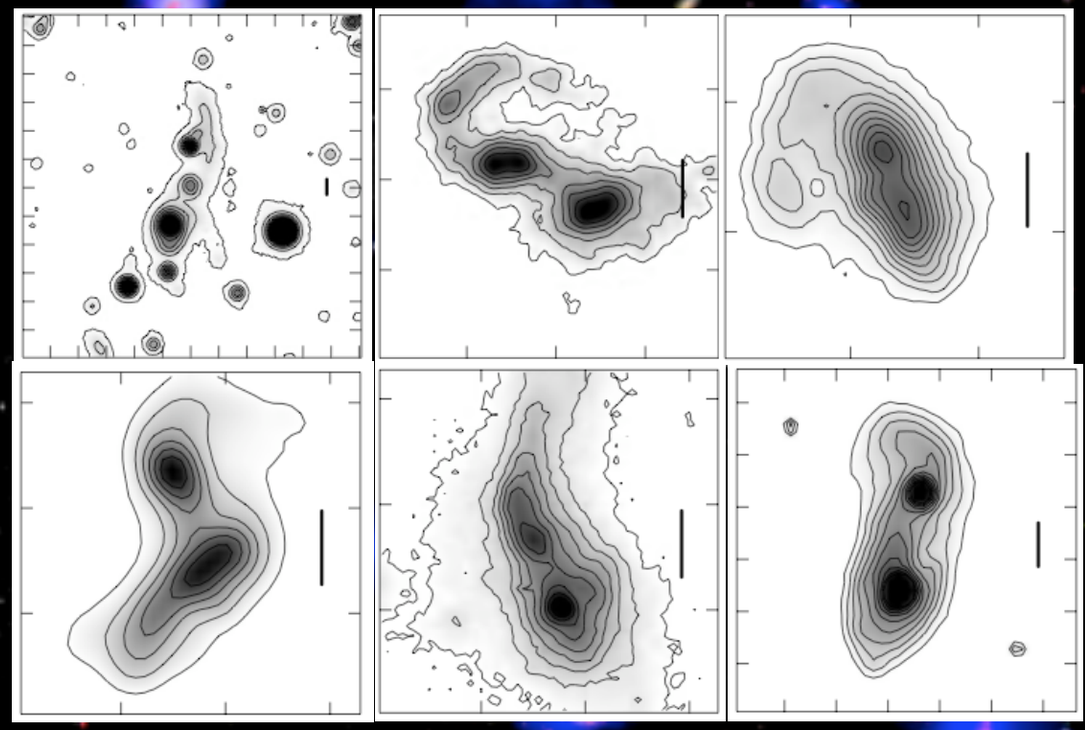
- The level of enhanced depends on the environment, and is deeper in the outerskirts of clusters of galaxies (Martig et al., 2008)



Di Matteo et al., 2009

- All ULIRGs (with SFRs > 100 Mo/yr) are advanced mergers

- Simulations have difficulties to reproduce extreme starburst unless an unrealistic gas fraction (for low z) is assumed in the colliding galaxies (Cox et al., 2008)



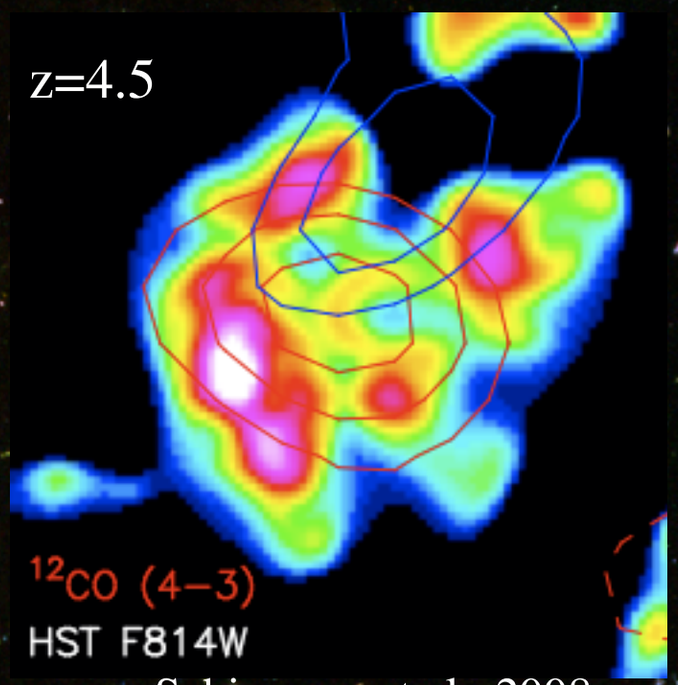
Duc et al., 1998

Star formation in high-z mergers

- Star Formation in distant (z=1) LIRG/ ULIRG (with SFR of a few 100 Mo/yr) takes place in normal spirals, including galaxies in a clumpy phase

Elbaz et al.,

- The SMGs, HyLIRG (with SFR>1000 Mo/yr) are probably advanced mergers



Schinnerer et al., 2008

=> Role of mergers: trigger extreme Star-Formation at each z range

Summary: role of mergers in galaxy evolution

Morphological evolution of galaxies:

- at low-z: main driver (outside clusters where additional effects may occur)
  formation of structures: SSCs, GCs, UCDs?
- at high-z: secular evolution of clumpy disks, through cold gas accretion, may form present day spirals
- at intermediate z: controversial results: “disk rebuilding” scenario challenged

Star-formation

- at low and high z: most extreme bursts: ULIRGs to SMGs
- Whether most SF in Universe takes place through merging phase is challenged
- Strong environmental effects: avoid densest regions at low-z, not at intermediate ones

- Results obtained thanks to a coumpling between observations (kinematics of resolved galaxies) and simulations

Questions