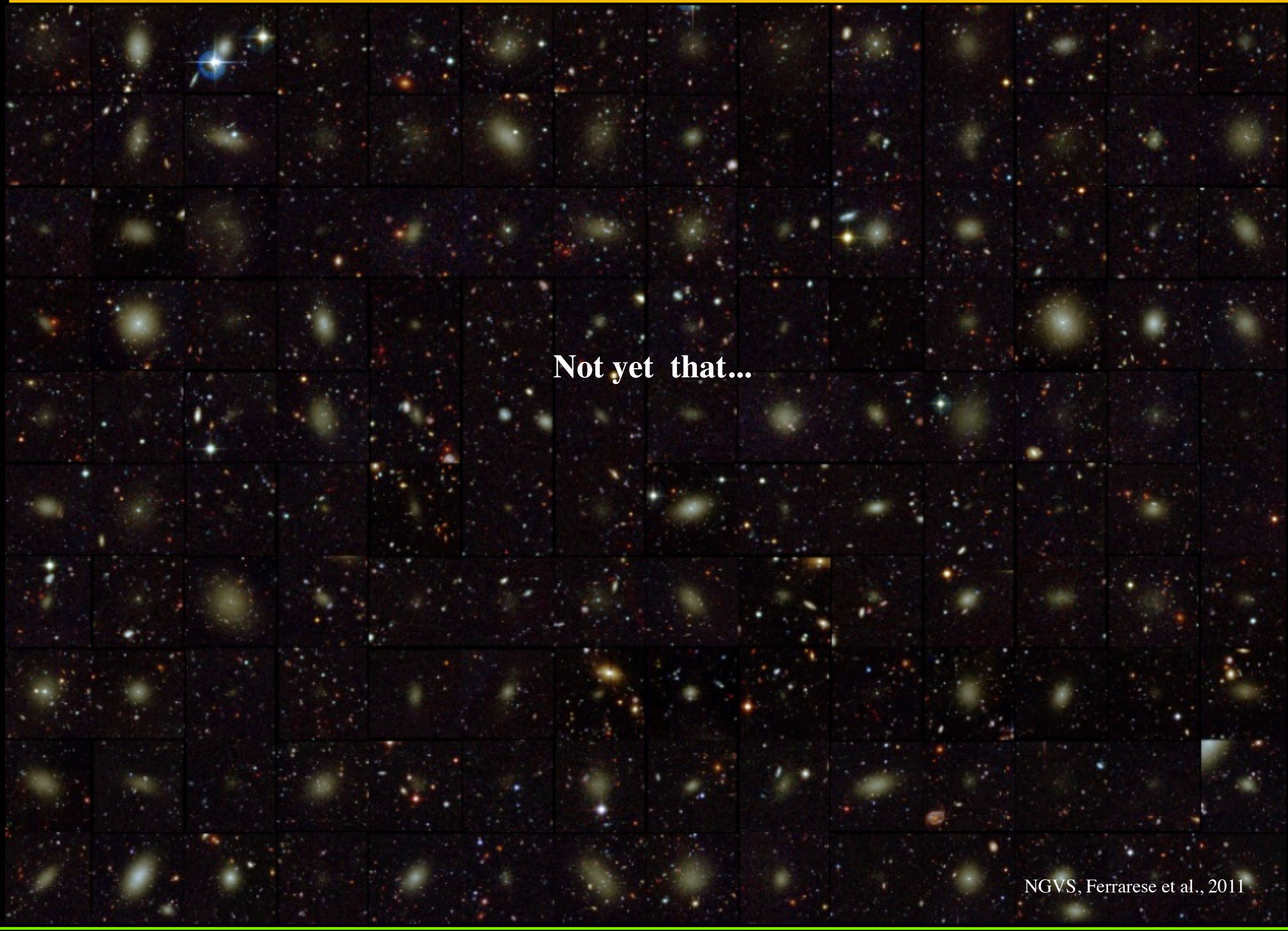
Kinematics of Tidal Dwarf Galaxies

Pierre-Alain Duc, AIM, Paris-Saclay

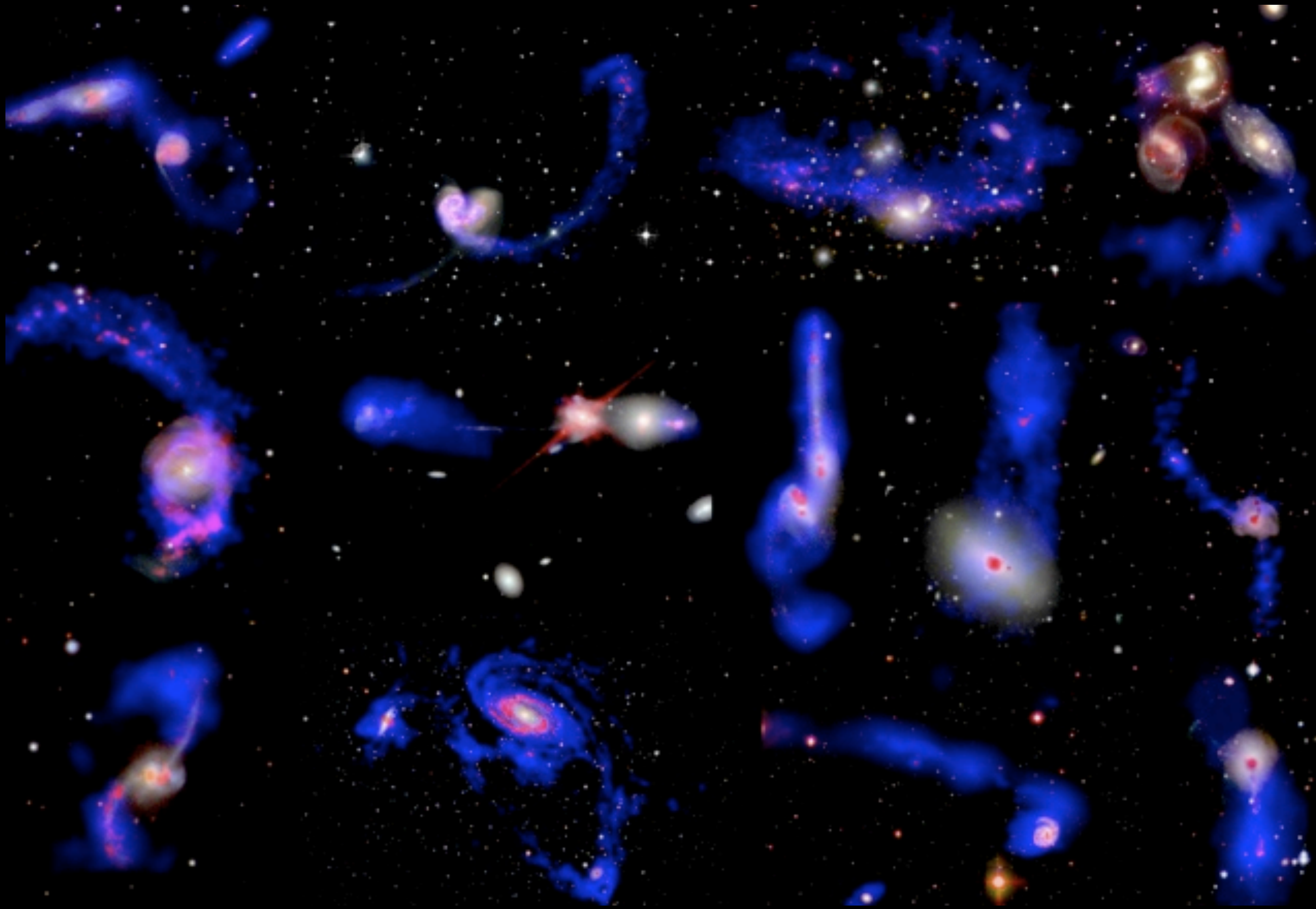
Hotel Director, room 1106

Santiago, April 4, 2011

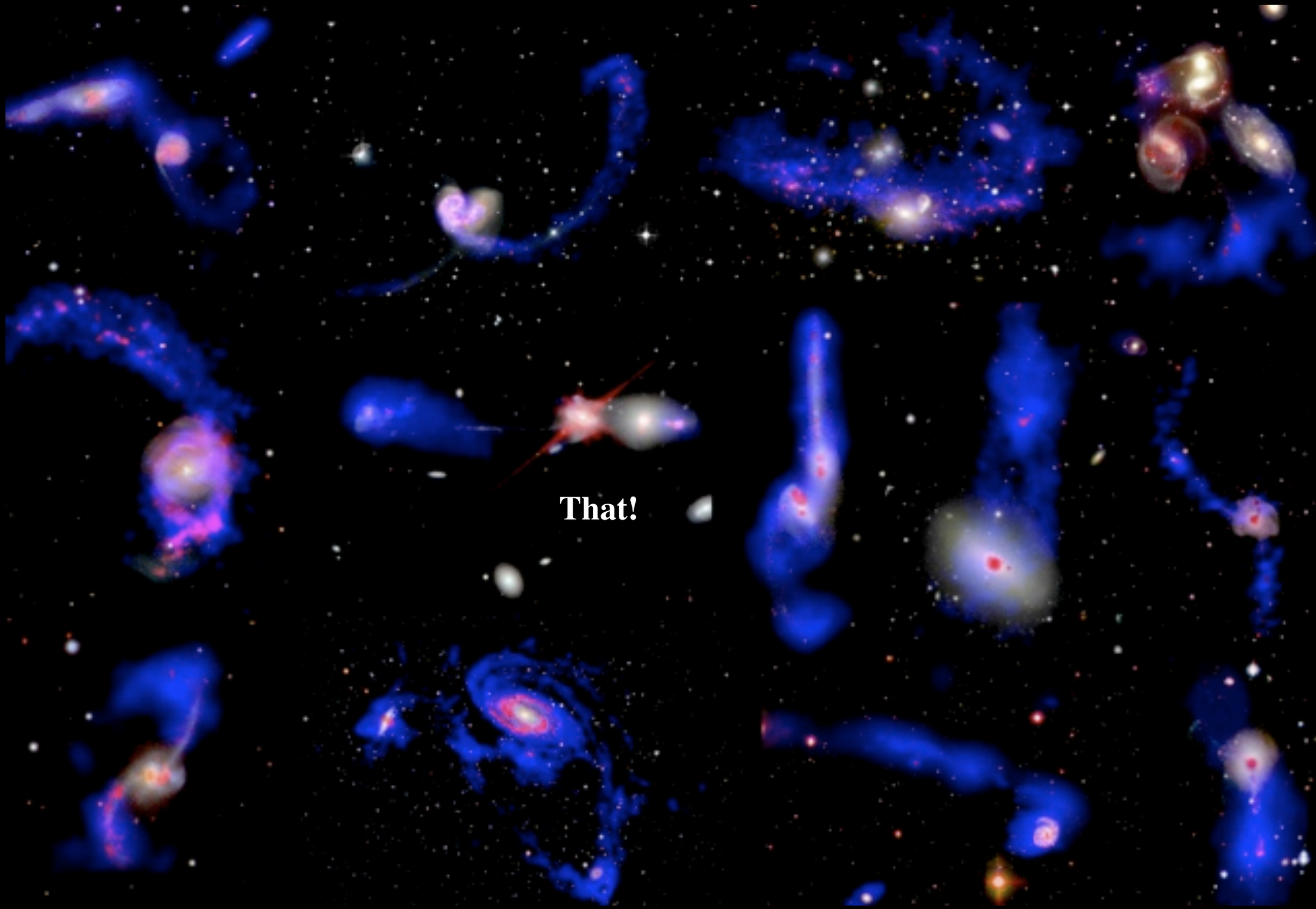
Tidal Dwarf Galaxies ?



Tidal Dwarf Galaxies ?

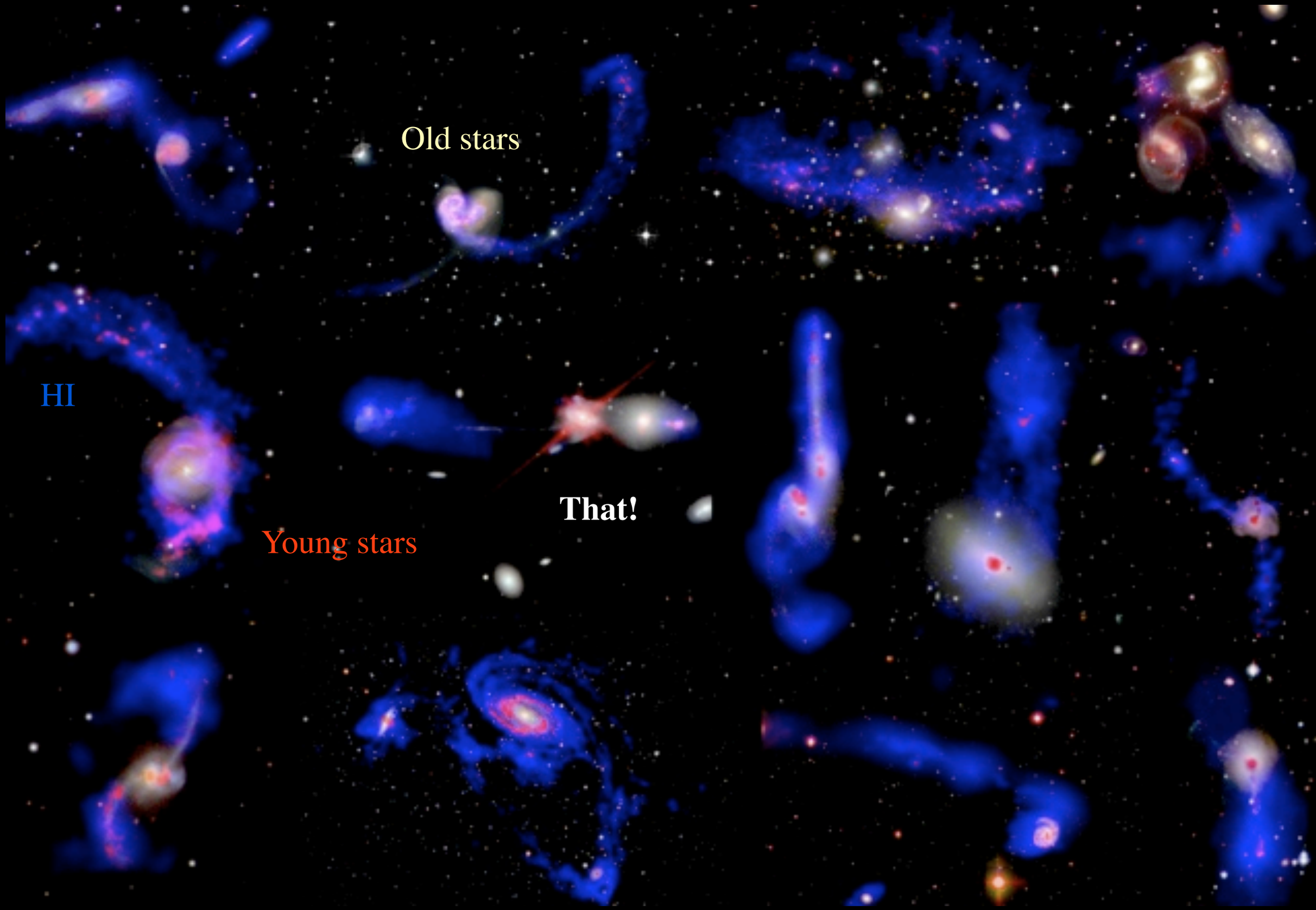


Tidal Dwarf Galaxies ?

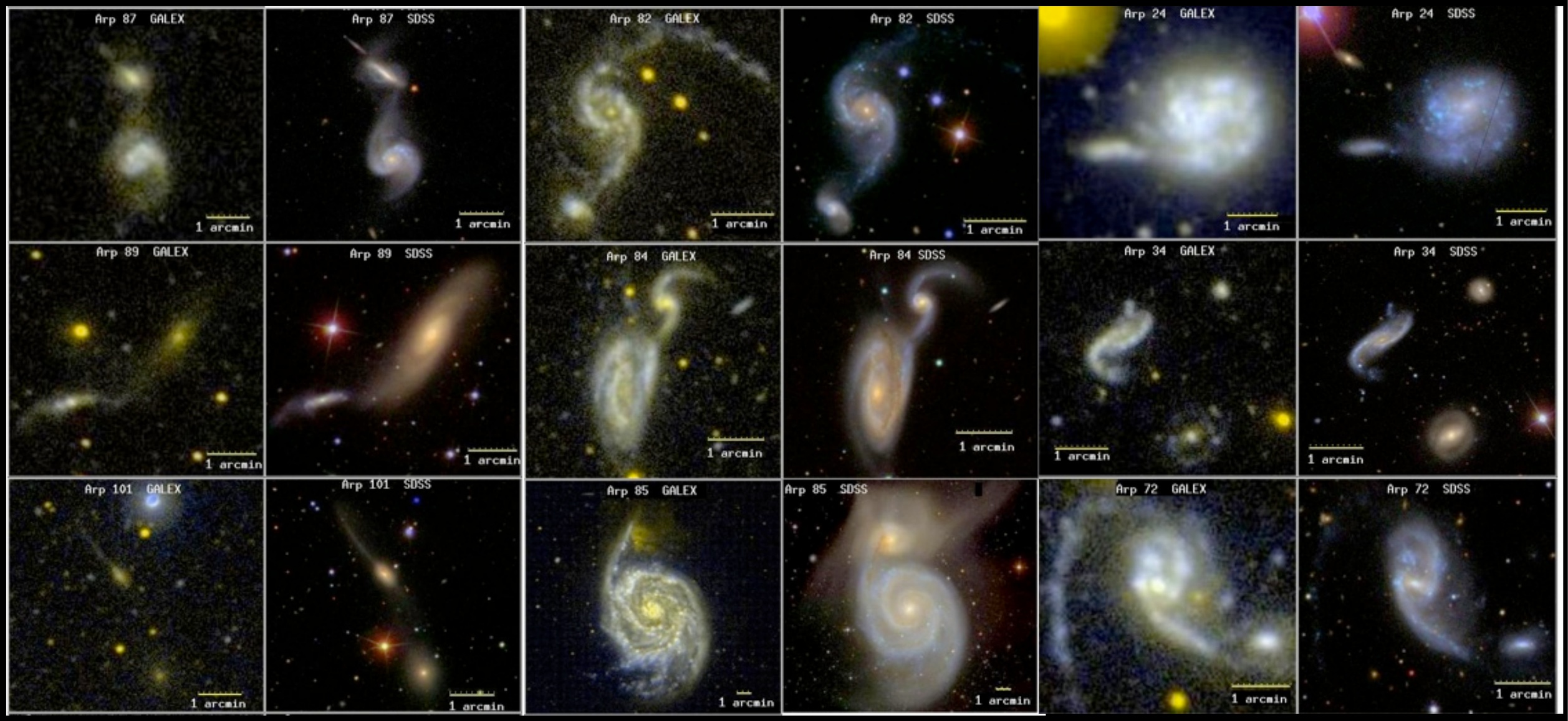


That!

Tidal Dwarf Galaxies ?



Or that...

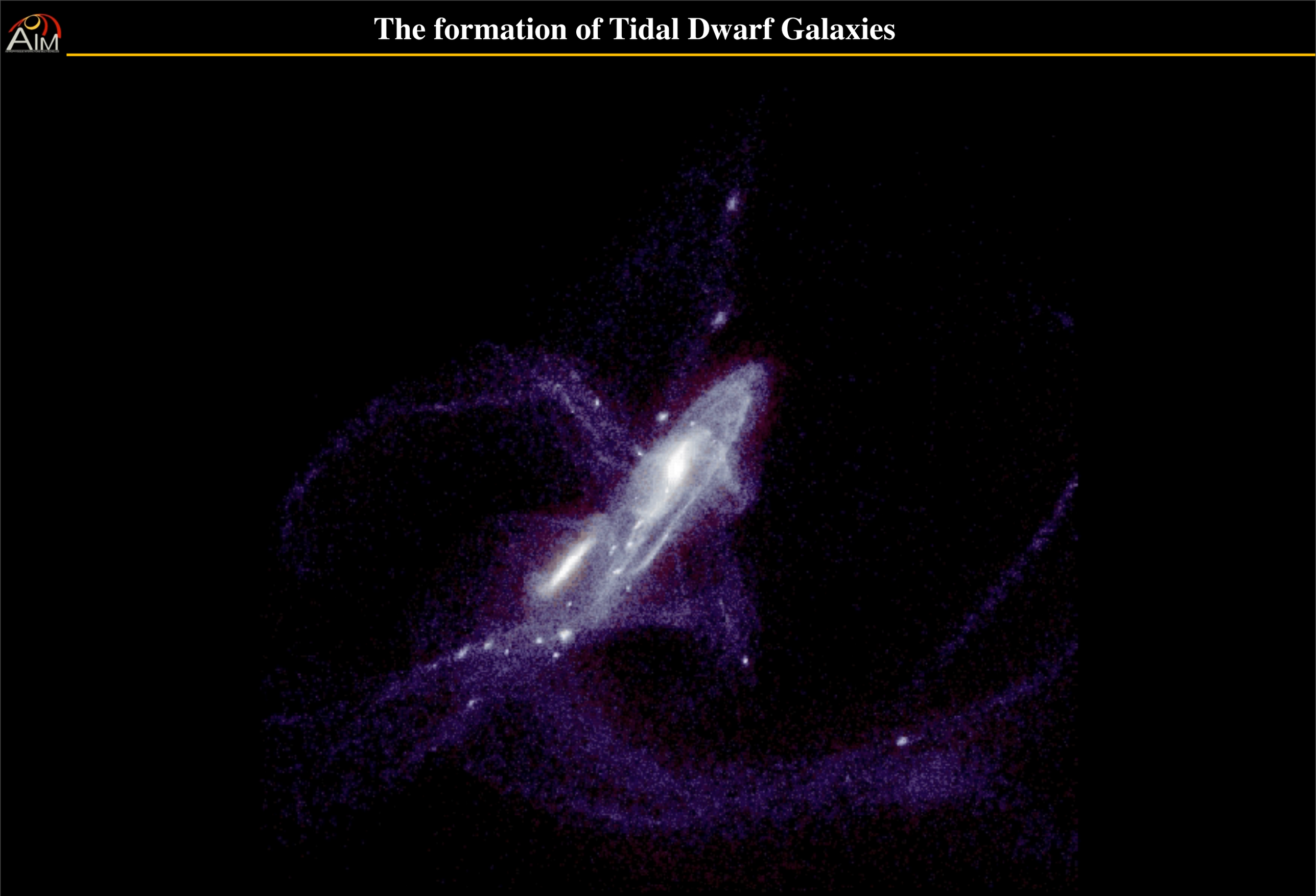


Star-formation in collisional debris

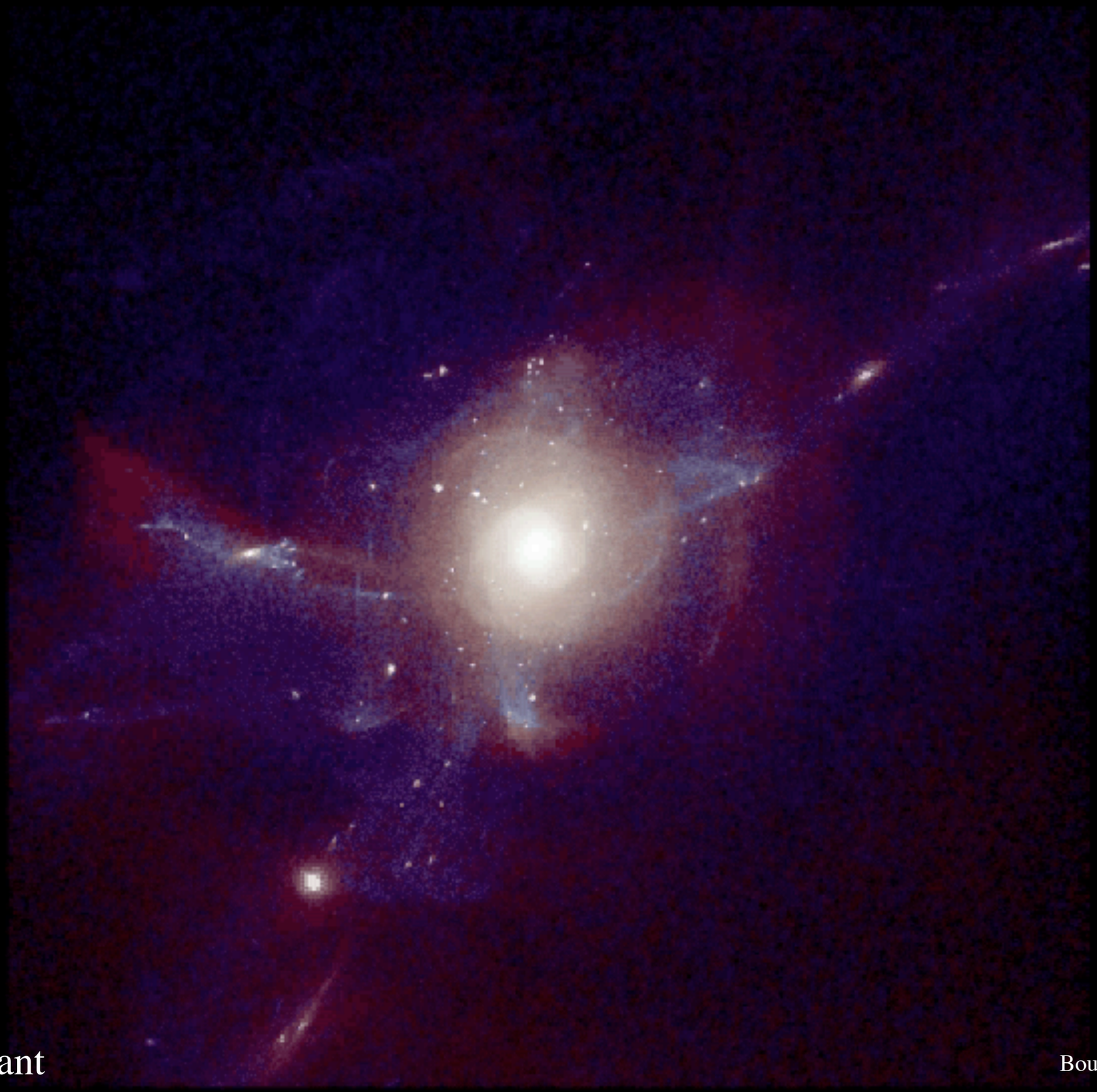
Hancock, et al., 2009
Torres-Flores, et al., 2008
Smith et al., 2010
Boquien et al., 2009,2010

The formation of Tidal Dwarf Galaxies

The formation of Tidal Dwarf Galaxies



The formation of Tidal Dwarf Galaxies

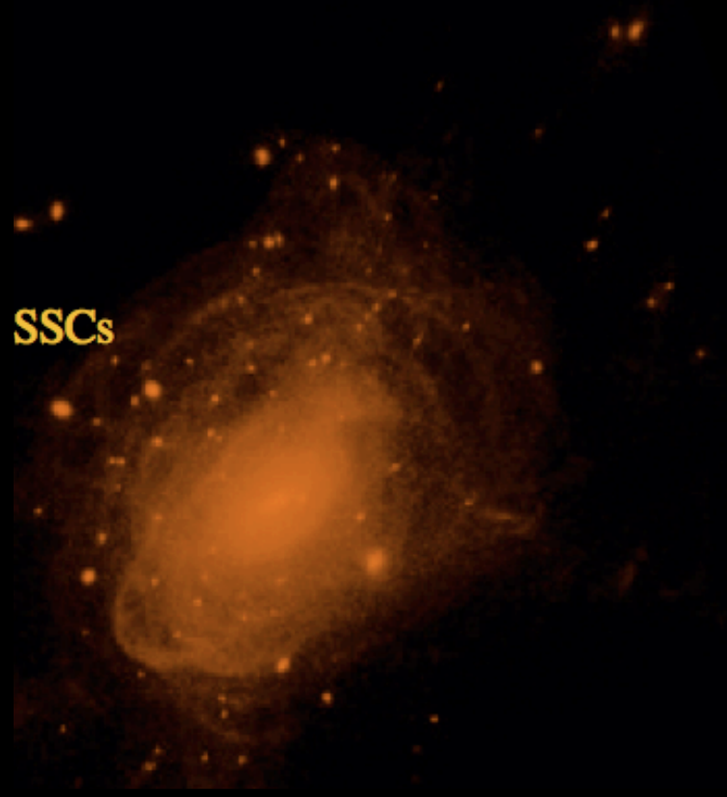


Merger remnant

Bournaud, Duc & Emsellem, 2008

The formation of Tidal Dwarf Galaxies

- Various stellar objects produced in mergers:
Pressure supported objects:
SSCs (-> GCs)



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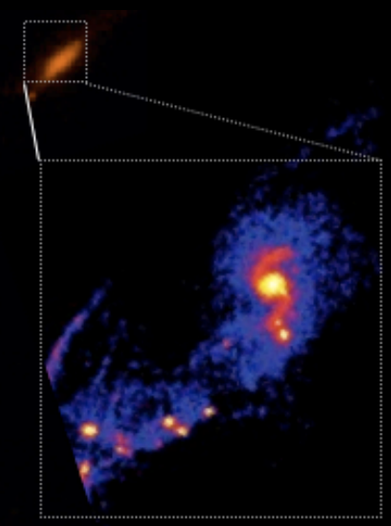
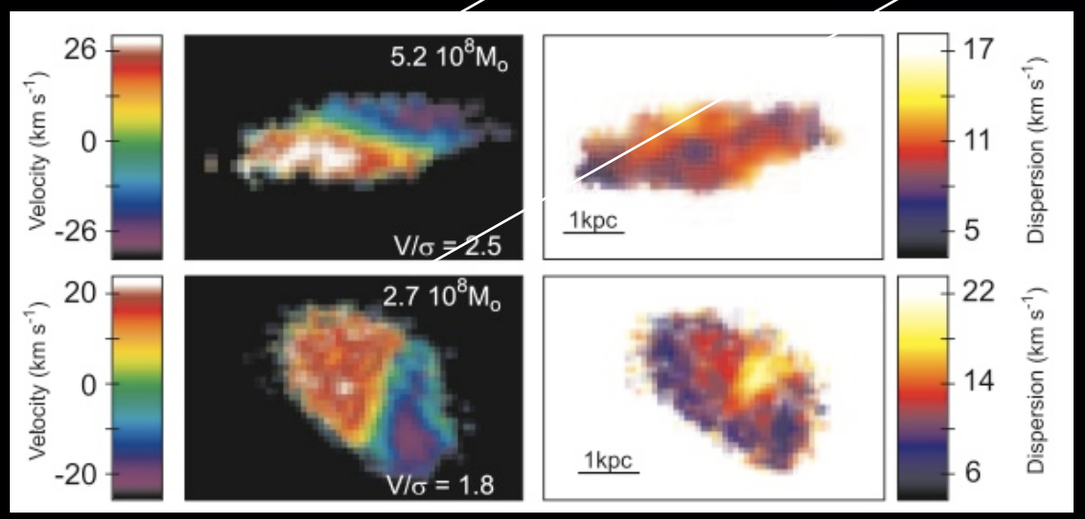


Bournaud, Duc & Emsellem, 2008



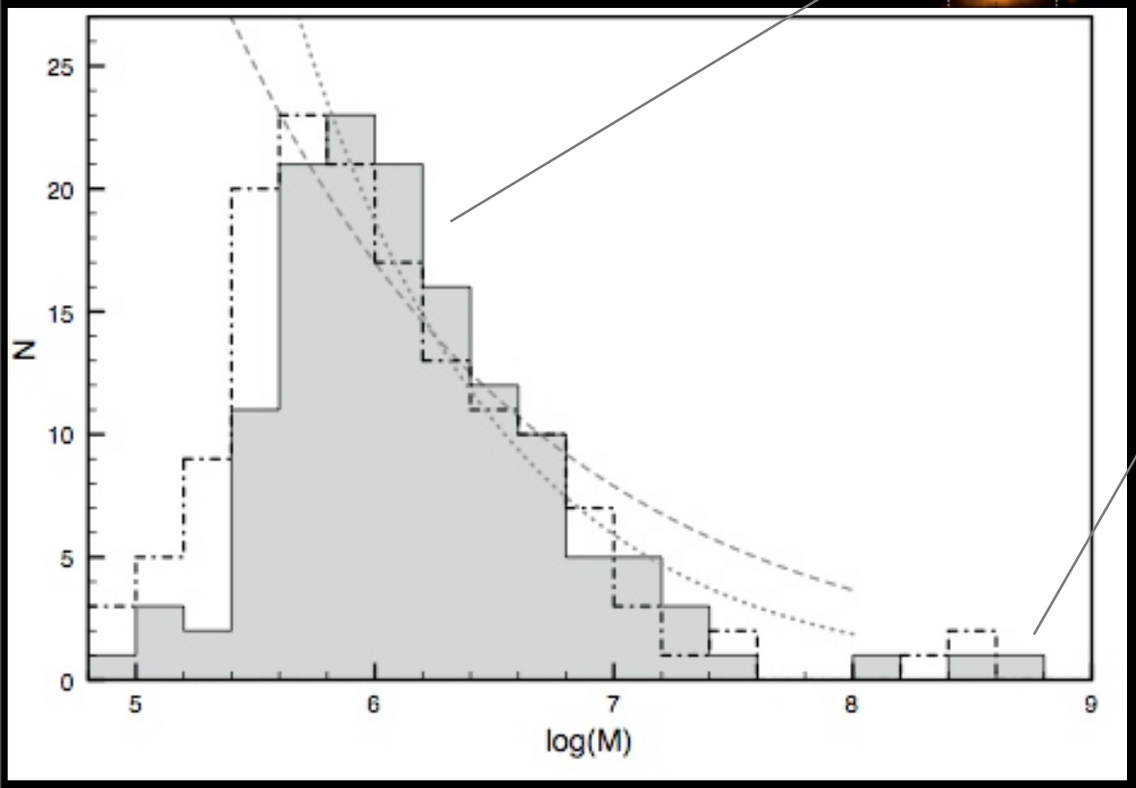
• TDGs are massive gravitationally bound, rotating objects formed within collisional debris

The formation of Tidal Dwarf Galaxies

TDG

SSCs

TDGs

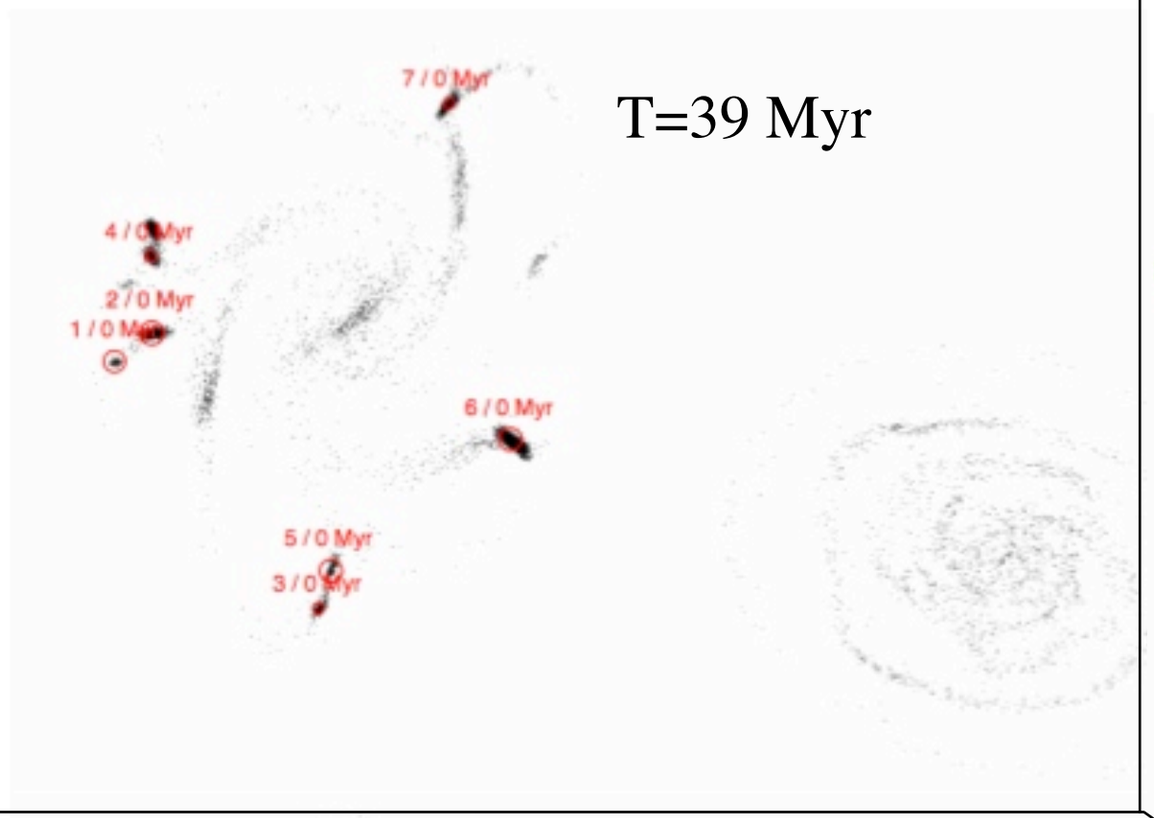


Bournaud, Duc & Emsellem, 2008

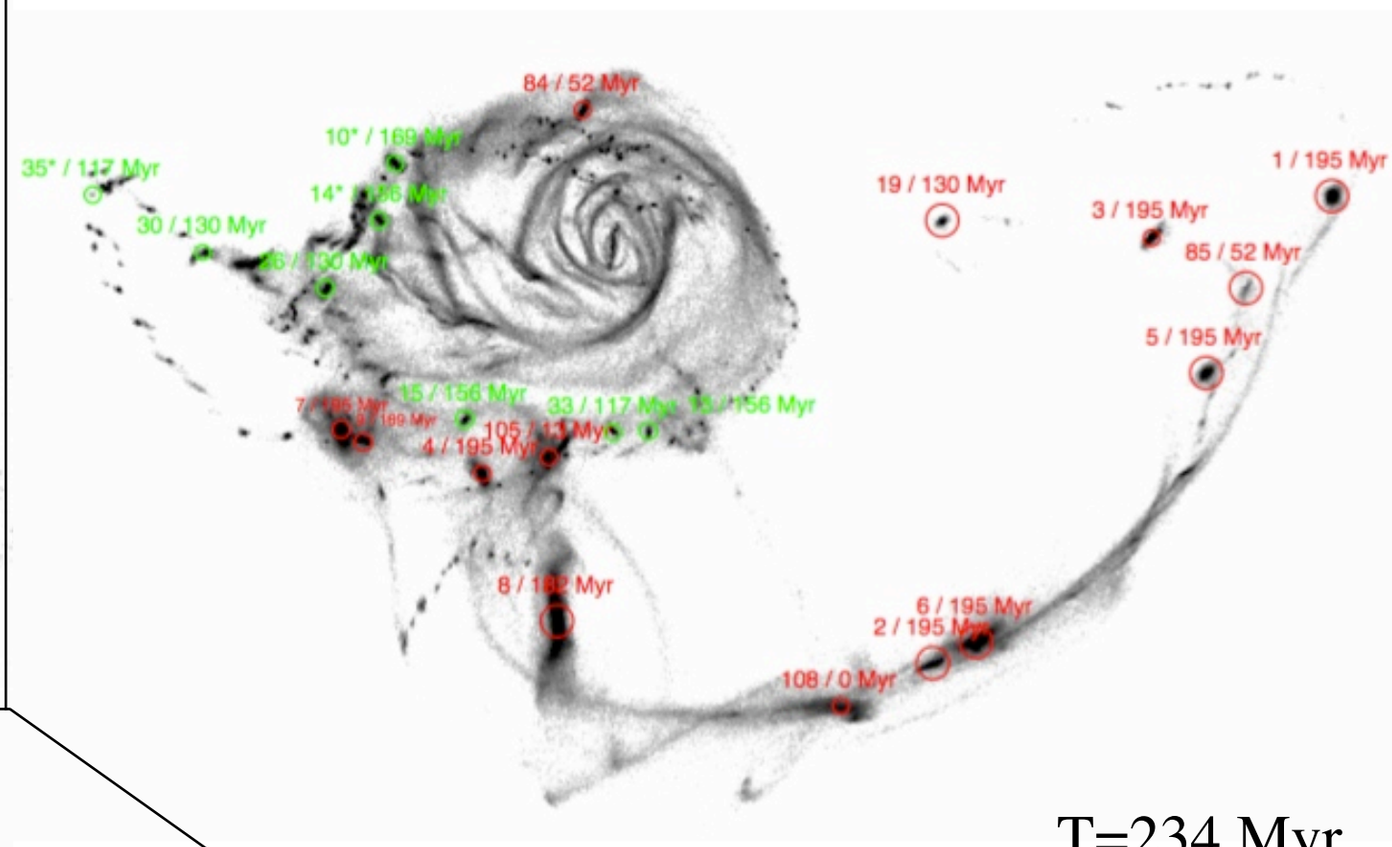
- A bimodality in the mass distribution of the objects formed during the collision

➡ Mass-dependent mode of formation or a transformation of one class into another?

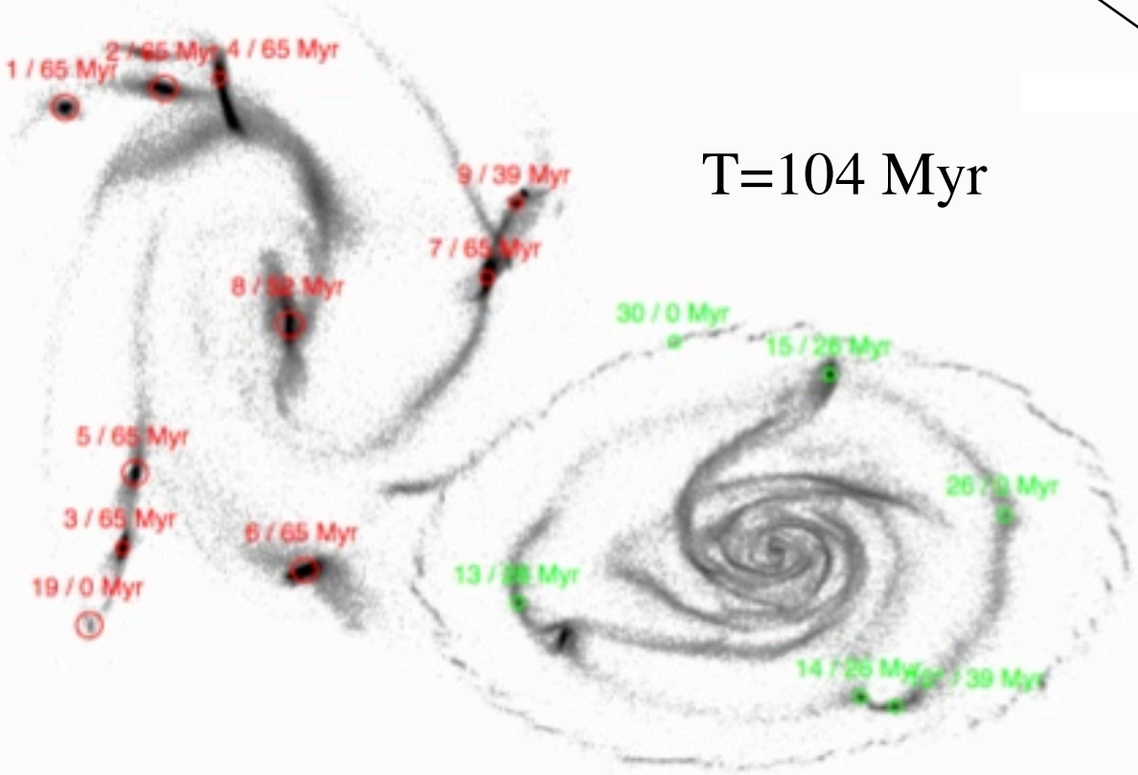
The formation of Tidal Dwarf Galaxies



T=39 Myr



T=234 Myr



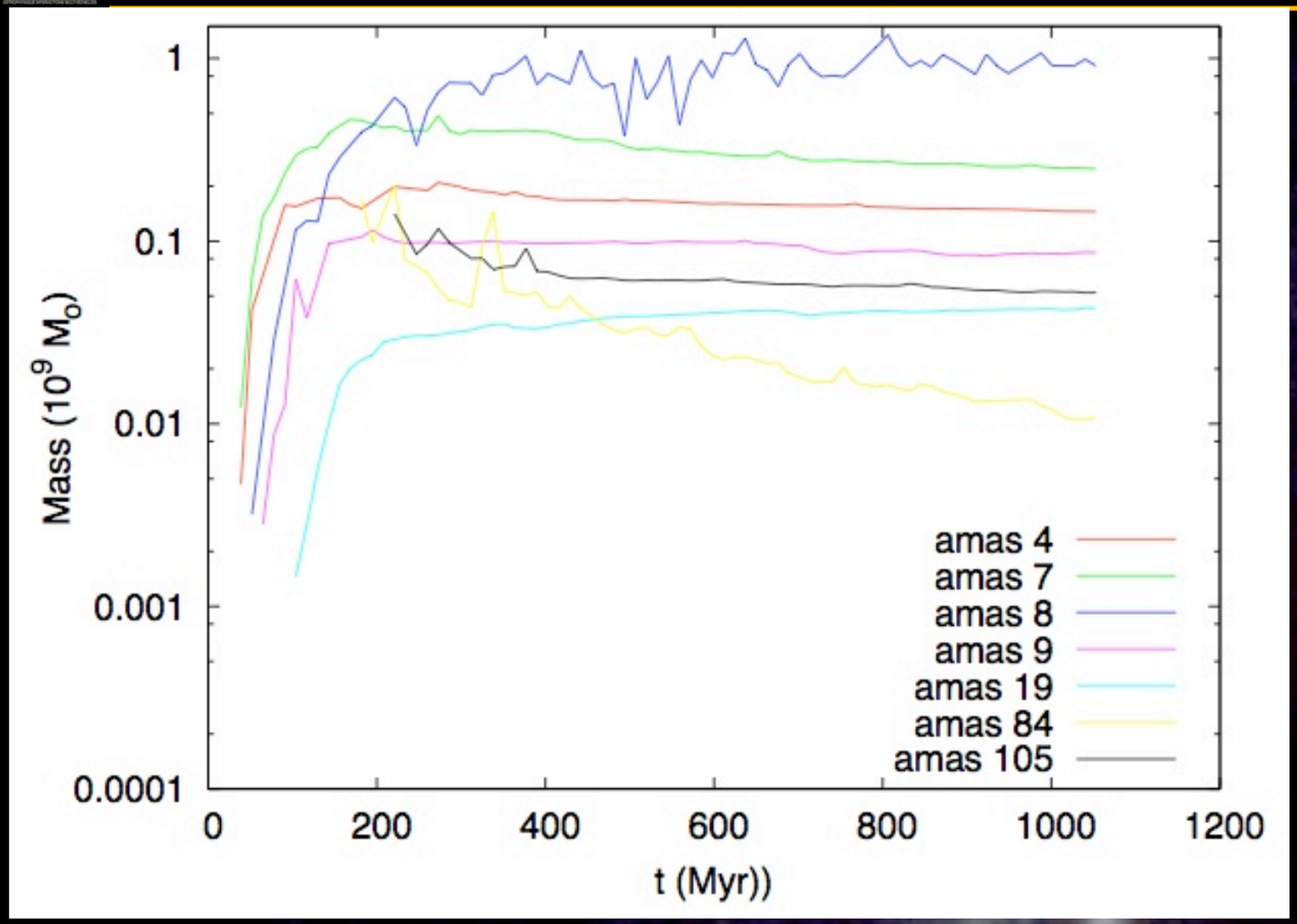
T=104 Myr

Belles et al 2011 in prep

➡The massive TDGs form during the initial stages of the collision

From local gravitational collapse (see Elmegreen et al., 1993)

The formation of Tidal Dwarf Galaxies

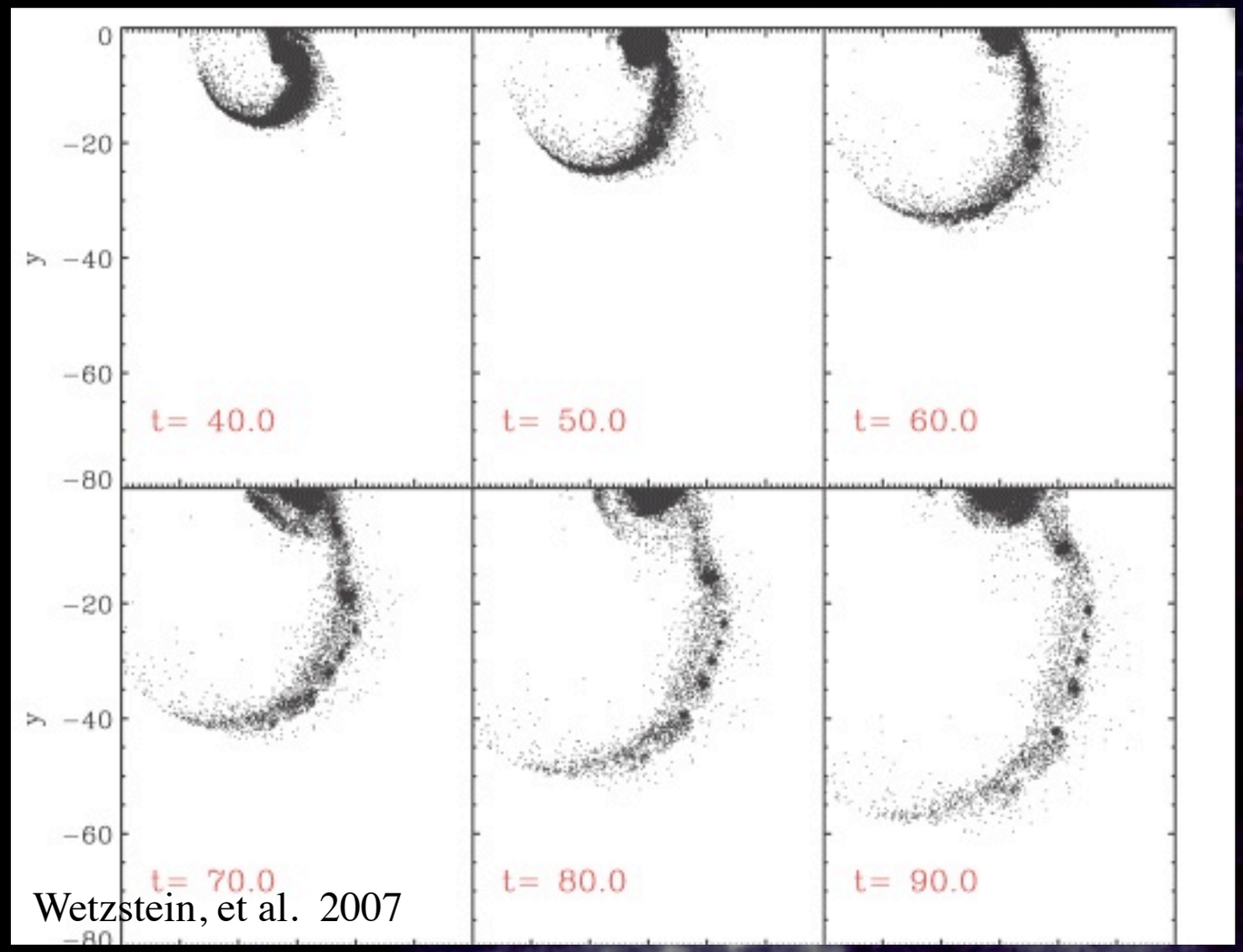


Belles, Miralles et al 2011, in prep

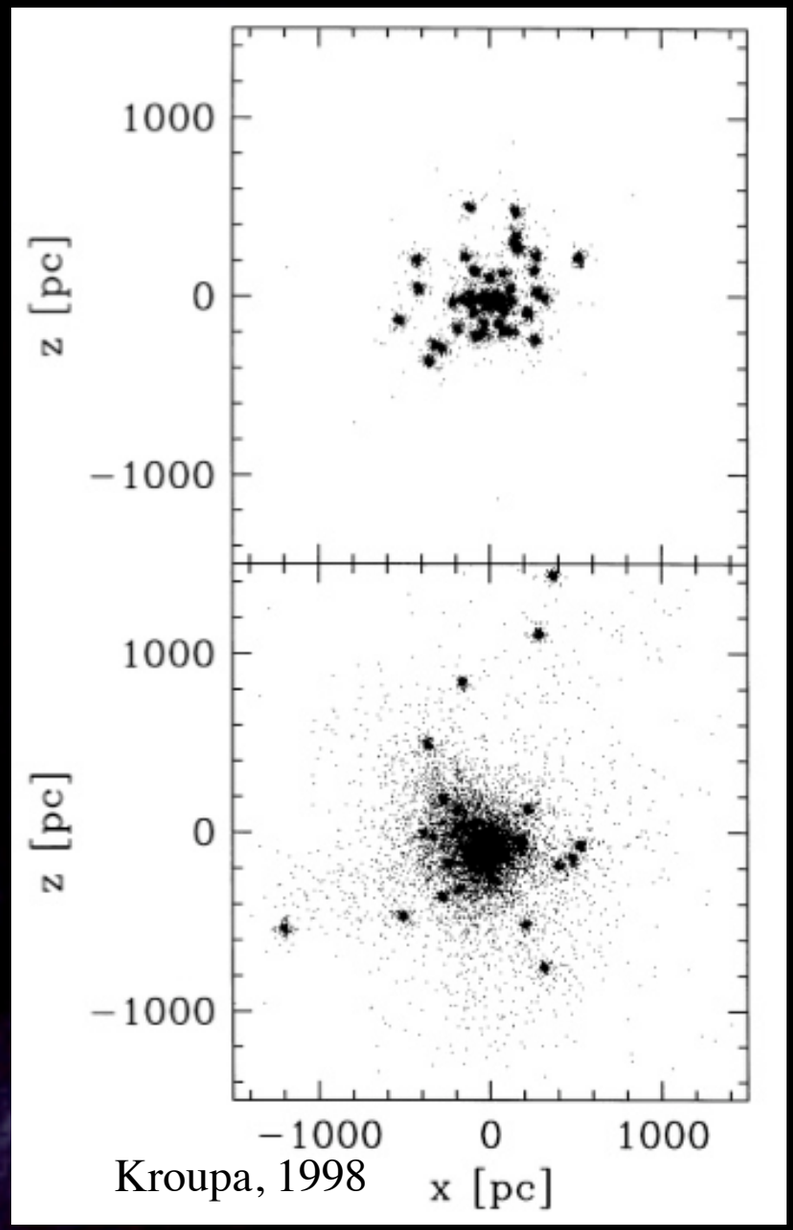
- The TDGs acquire rapidly all their mass and rotation speed.

➡A top-down process for the formation of the massive TDGs... A scenario that apparently differs from the bottom-up ones proposed earlier

The formation of Tidal Dwarf Galaxies: alternative, bottom-up scenarios



Wetzstein, et al. 2007

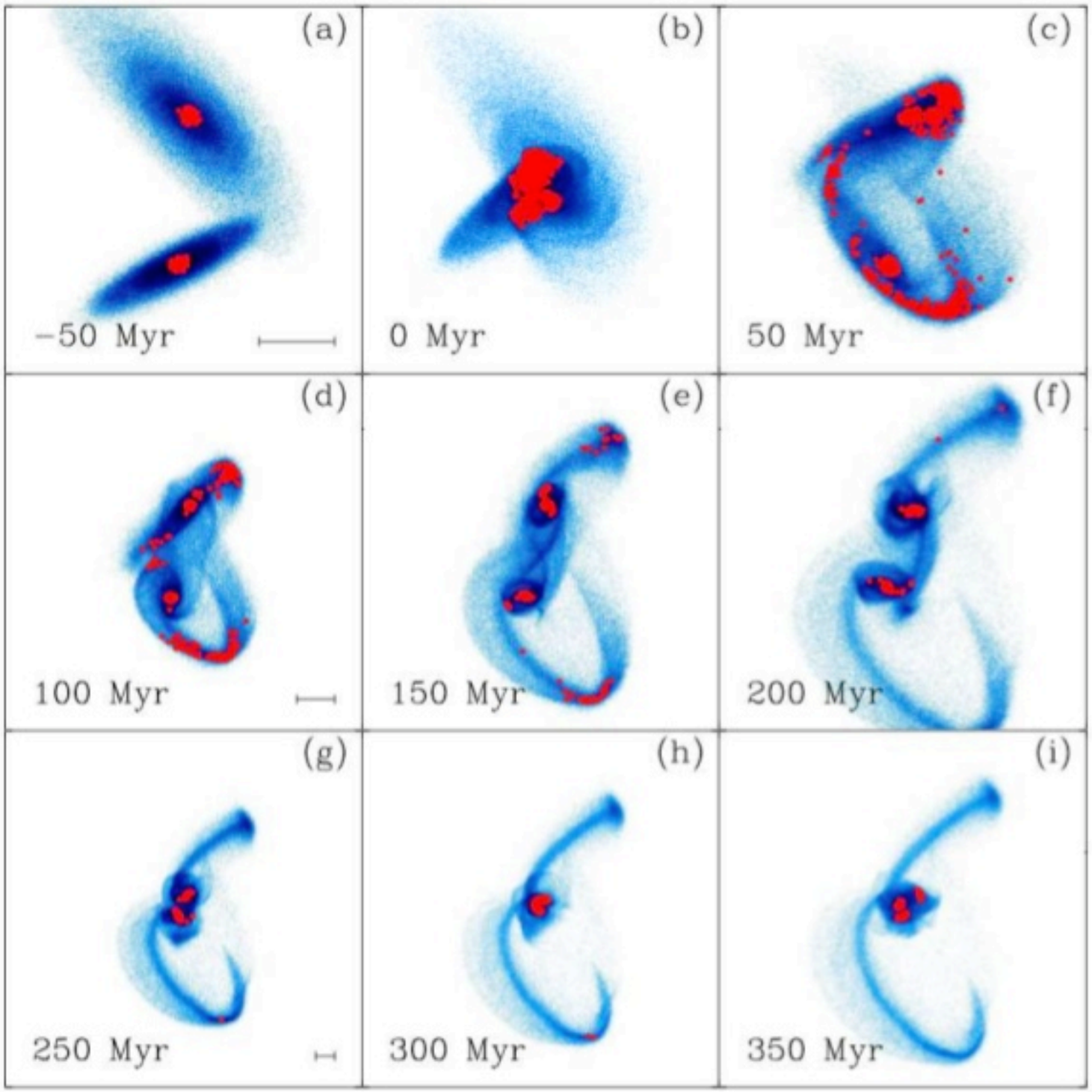


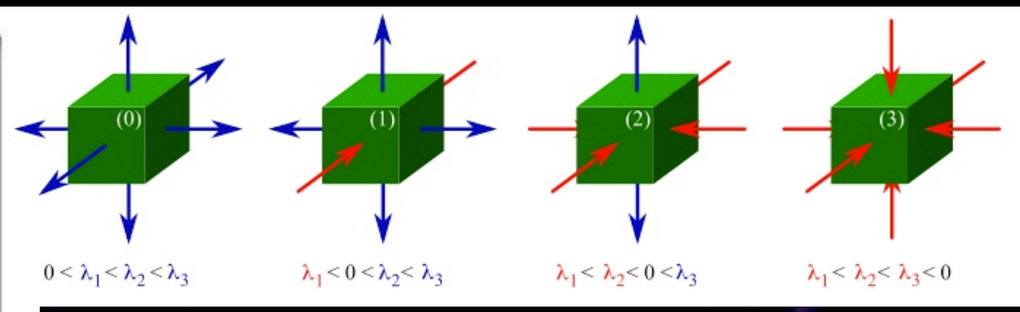
Kroupa, 1998

- Tidal dwarf galaxies may result from the growing of local stellar instabilities (Barnes & Hernquist, 1992)
- But could be particle noise (Wetzstein et al., 2007)

- Tidal dwarf galaxies may result from the merging of SSCs (Kroupa, 1998)

The formation of Tidal Dwarf Galaxies: alternative scenarios





- Tides may be extensive and/or compressive

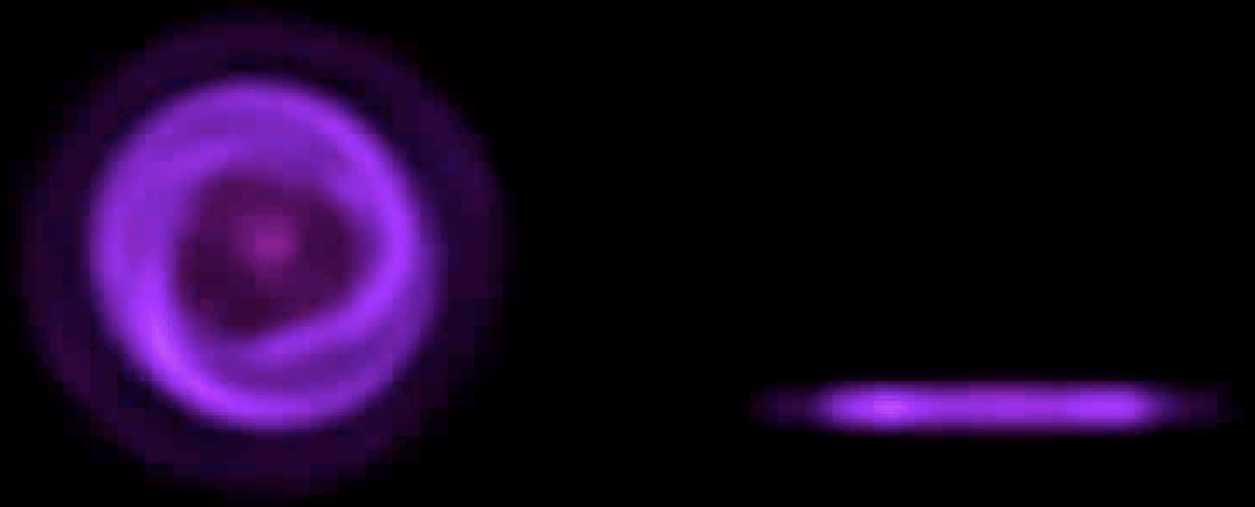
- Star-forming regions and star clusters are preferentially located in regions where the tides are fully compressive

- The fully compressive mode either favors the SSCs/TGGs formation or prevents their destruction

Renaud et al., 2009, 2010

The formation of Tidal Dwarf Galaxies: at high redshift

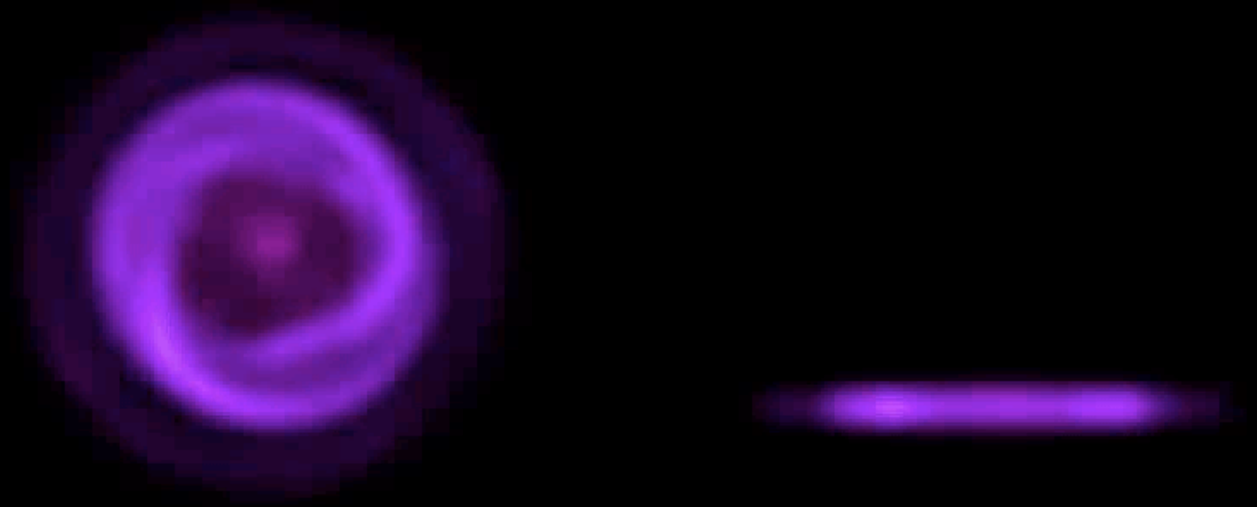
- More gas rich and unstable progenitors

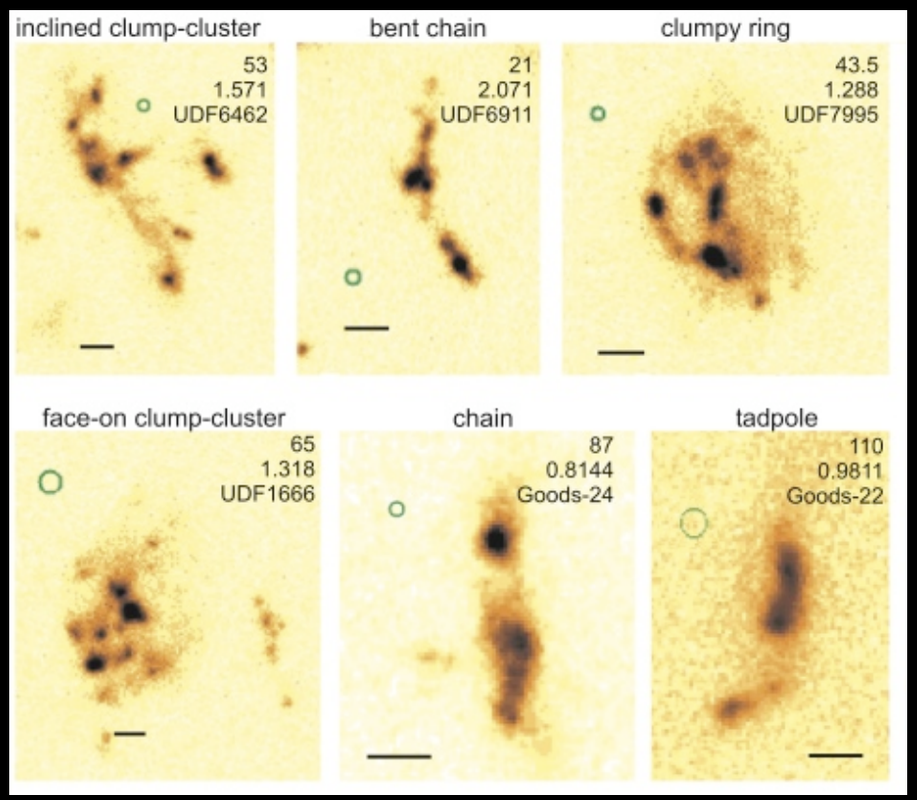


Bournaud et al., 2010

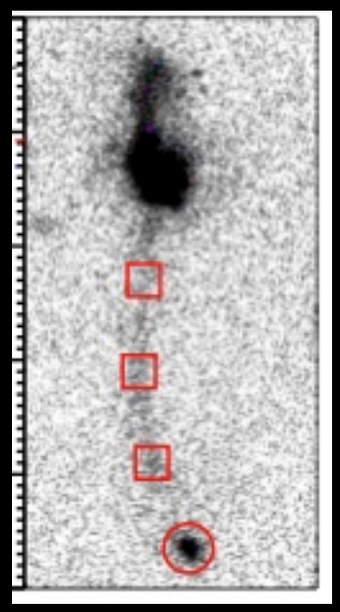
The formation of Tidal Dwarf Galaxies: at high redshift

- More gas rich and unstable progenitors





Elmegreen et al., 2007

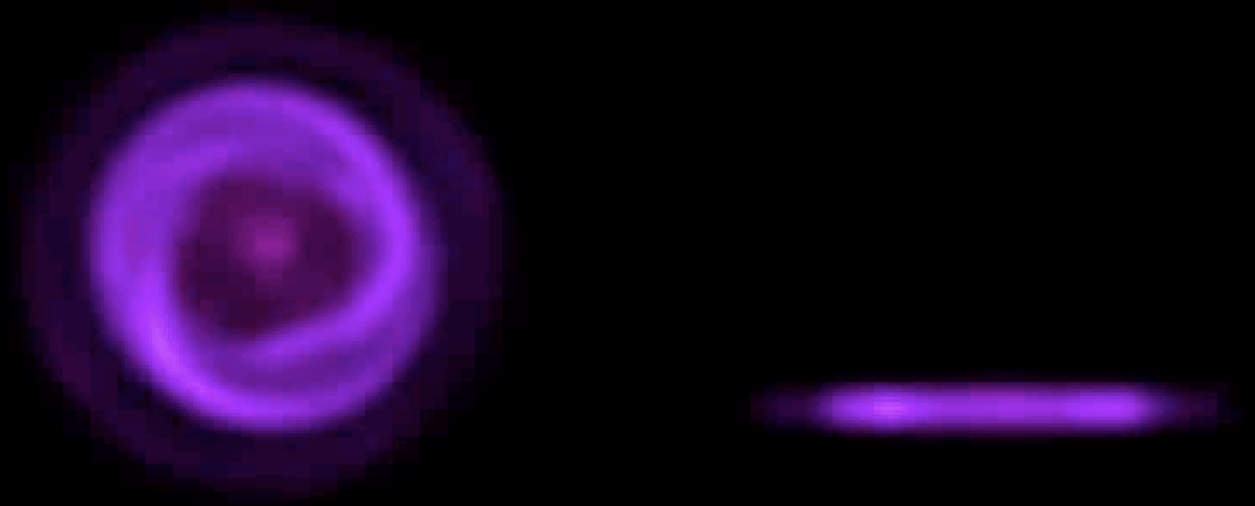


Zen et al., 2011

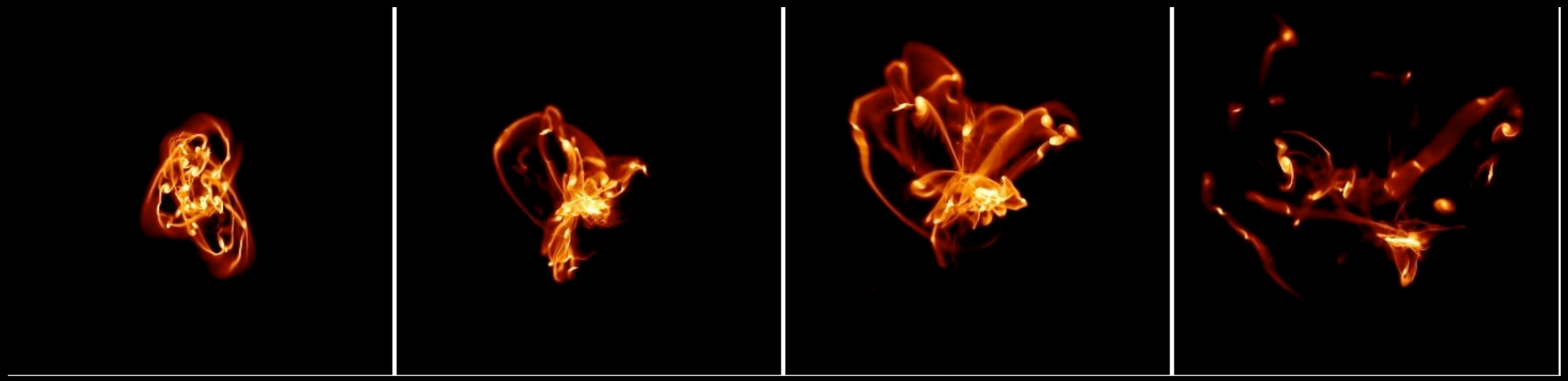
Bournaud et al., 2010

Tidal Dwarf Galaxies at high z

- More gas rich and unstable progenitors



➡ Their collision leads to the formation of numerous TDG-like objects ... but no tidal tails



Bournaud et al., 2010

Can the internal kinematics of Tidal Dwarfs tell about their origin?

Challenges:

✓Stellar kinematics not yet available

✓Relies on analysis of HI/CO/Ha datacubes with poor spatial resolution

✓projection effets

Back to observations: checking the kinematics of Tidal Dwarf Galaxies

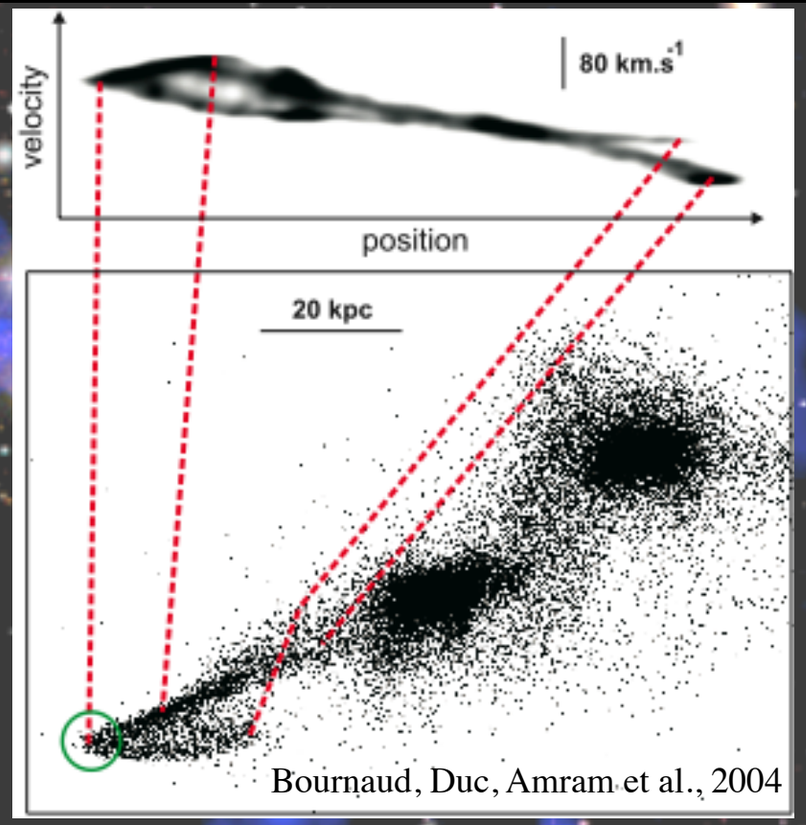
Challenges:

✓Stellar kinematics not yet available

✓Relies on analysis of HI/CO/Ha datacubes with poor spatial resolution

✓projection effets

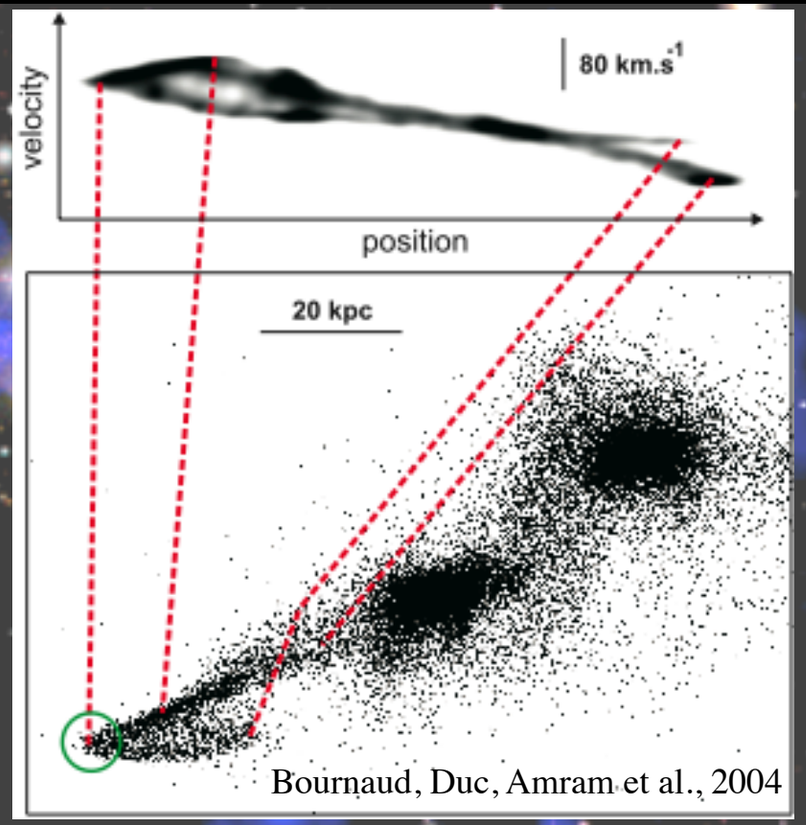
➡Disentangling real rotation motions from projected streaming motions along the tails



A change of the velocity gradient before the apparent tip of the tail tells about a projection effect

Dealing with projection effects

Disentangling real rotation curves from projected streaming motions along the tails

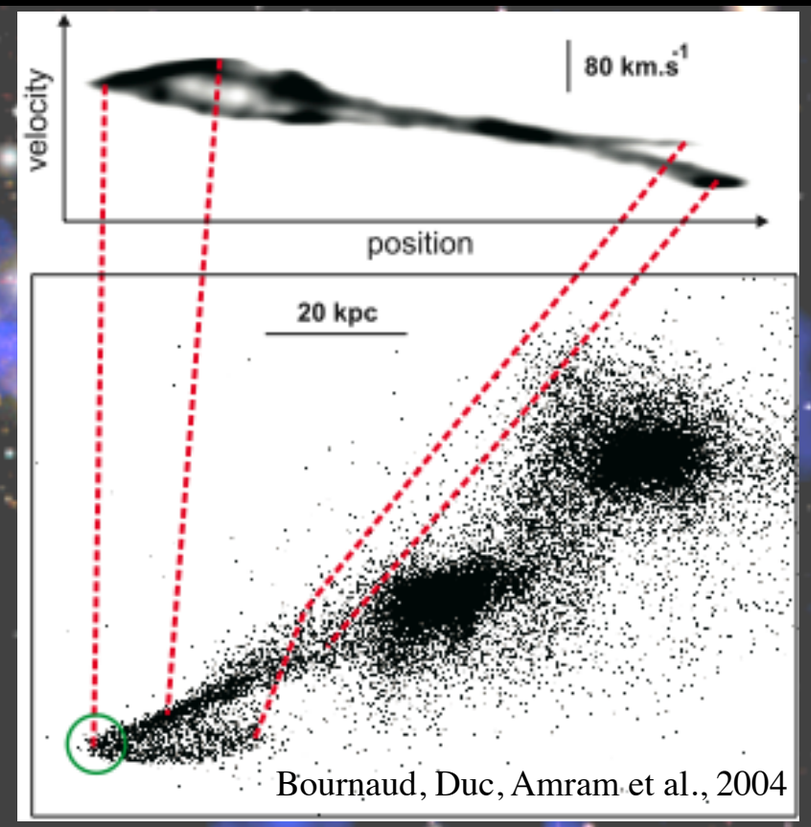


Arp 105

NGC 2992

Dealing with projection effects

Disentangling real rotation curves from projected streaming motions along the tails



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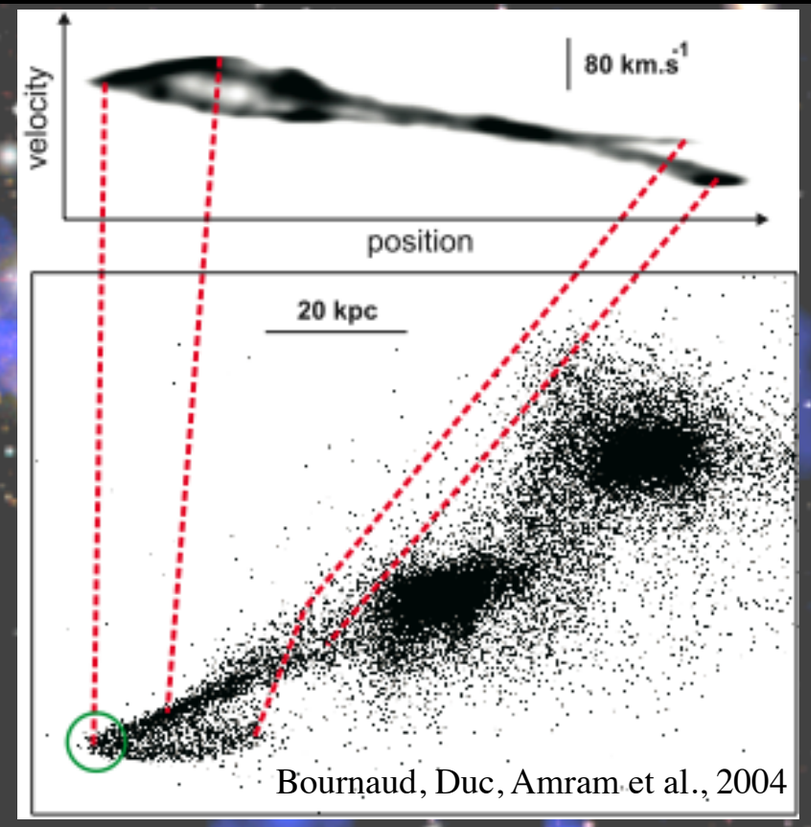
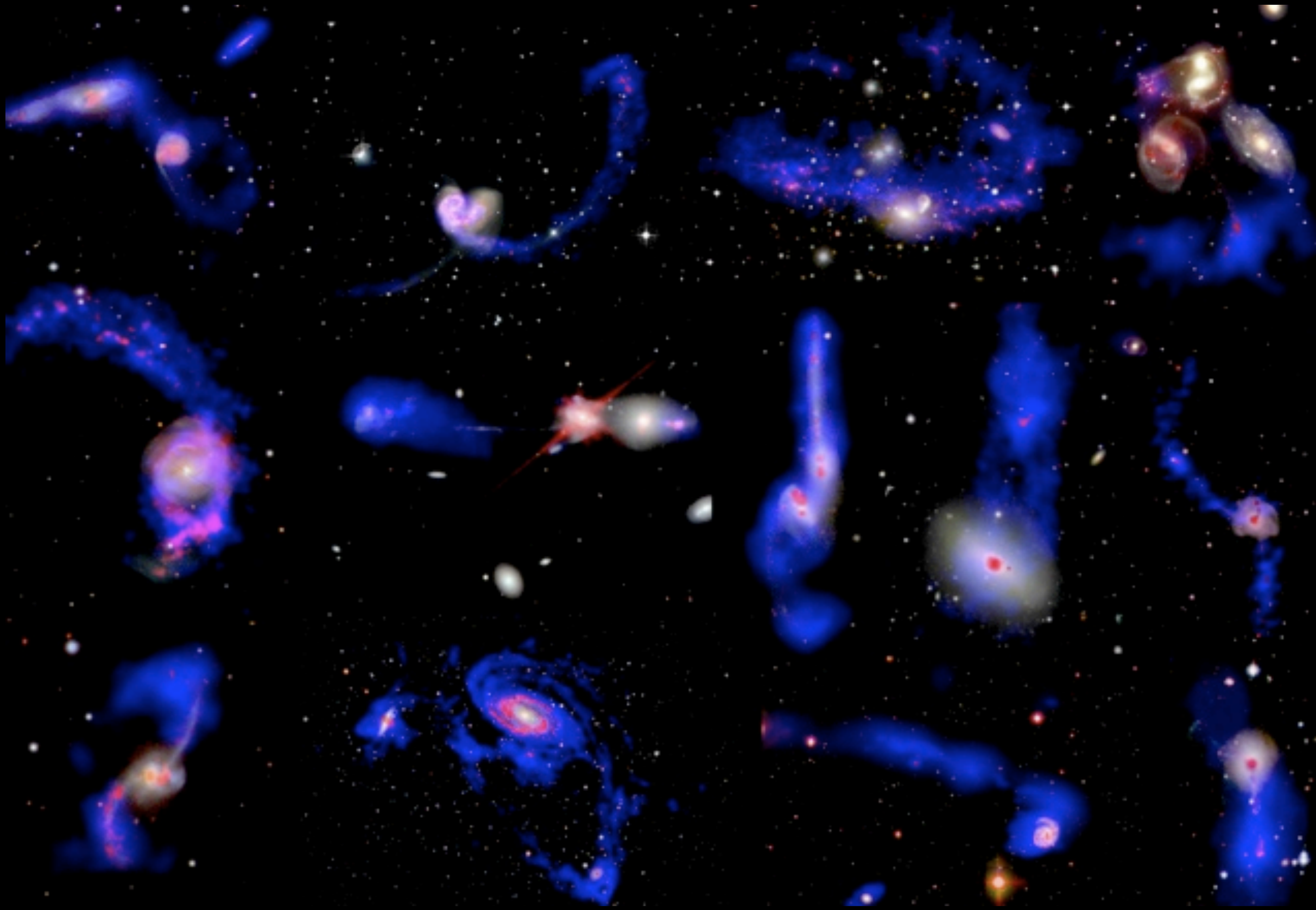
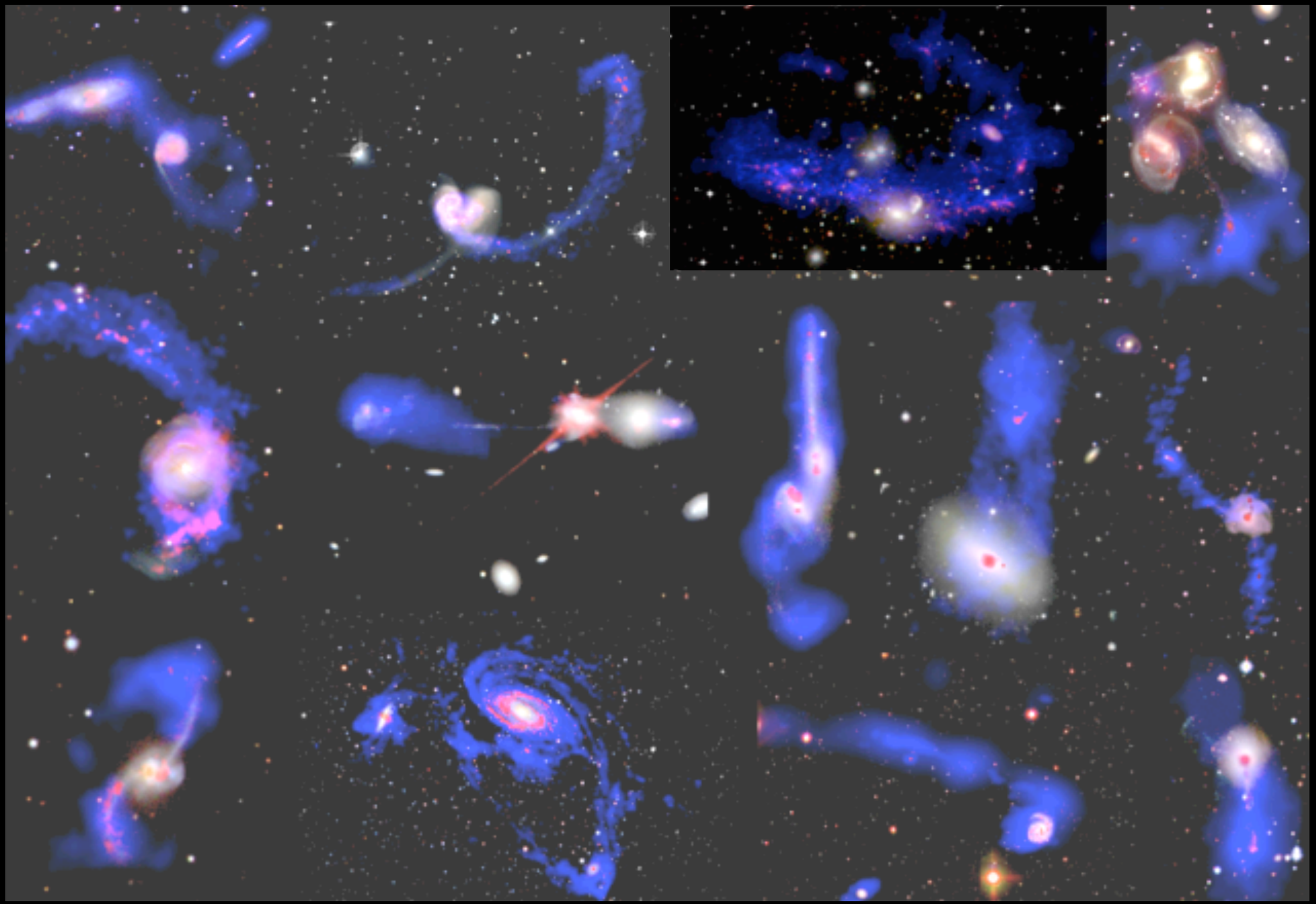


NGC 2992

Measuring the dynamical mass of TDGs



Measuring the dynamical mass of collisional debris



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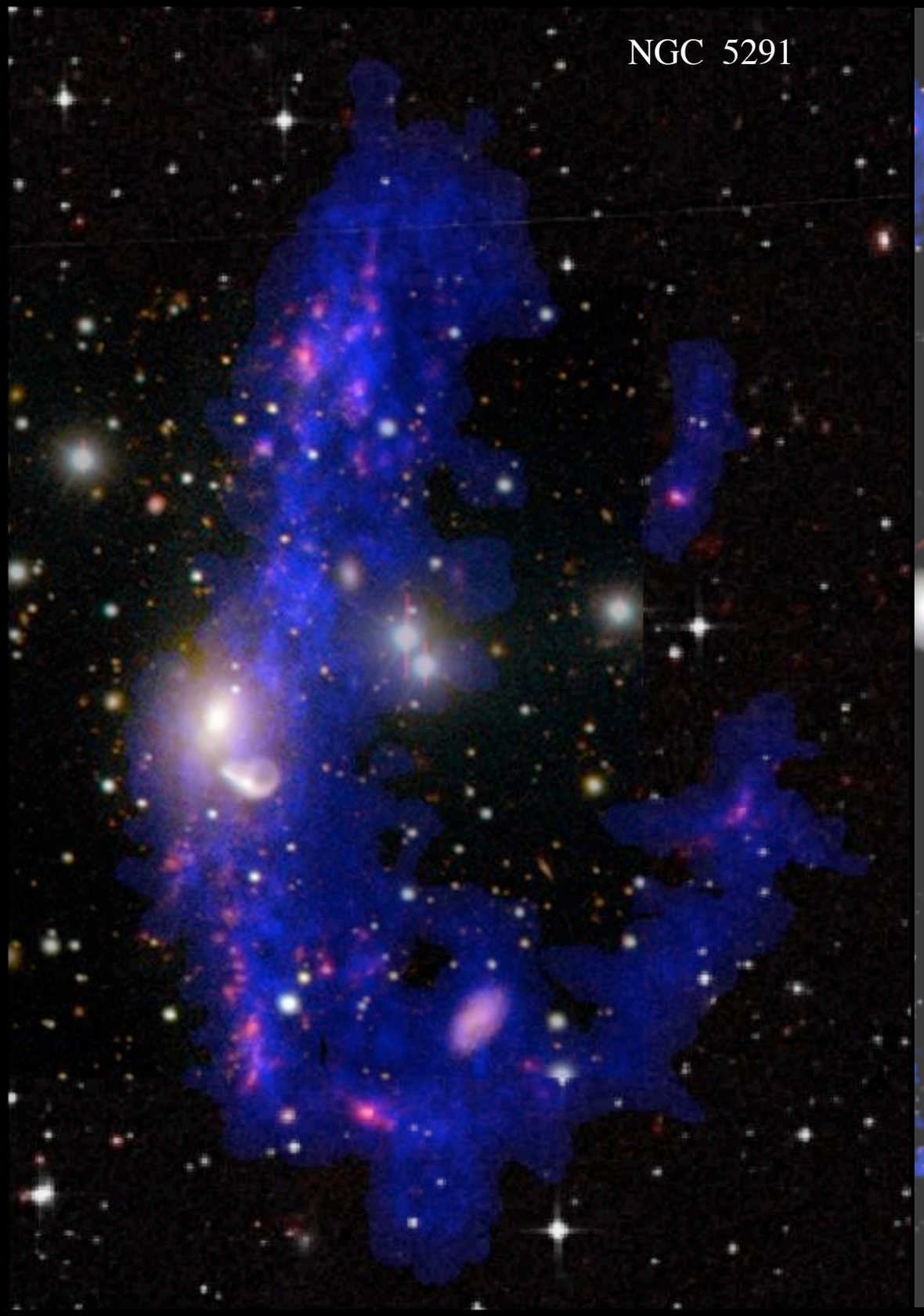

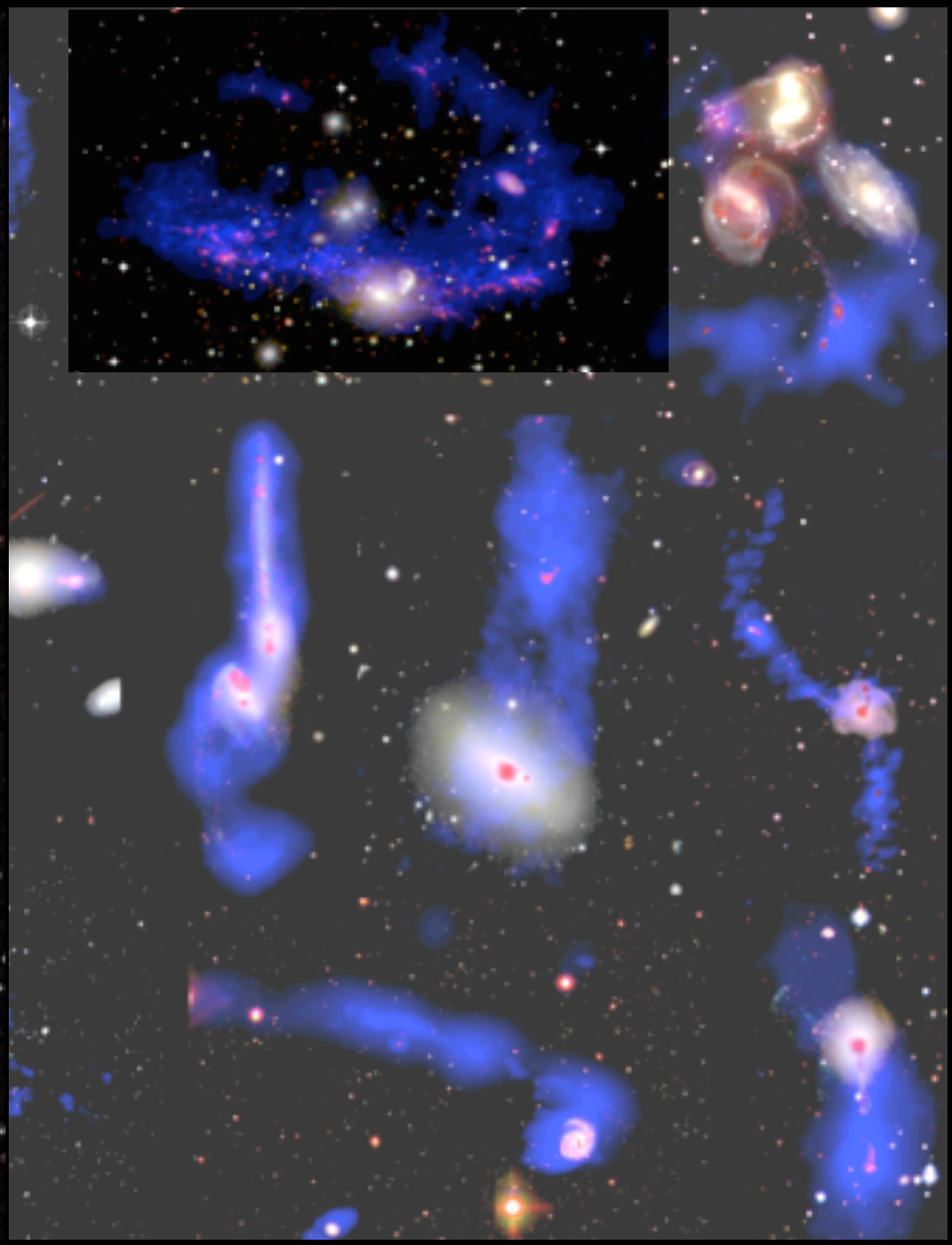

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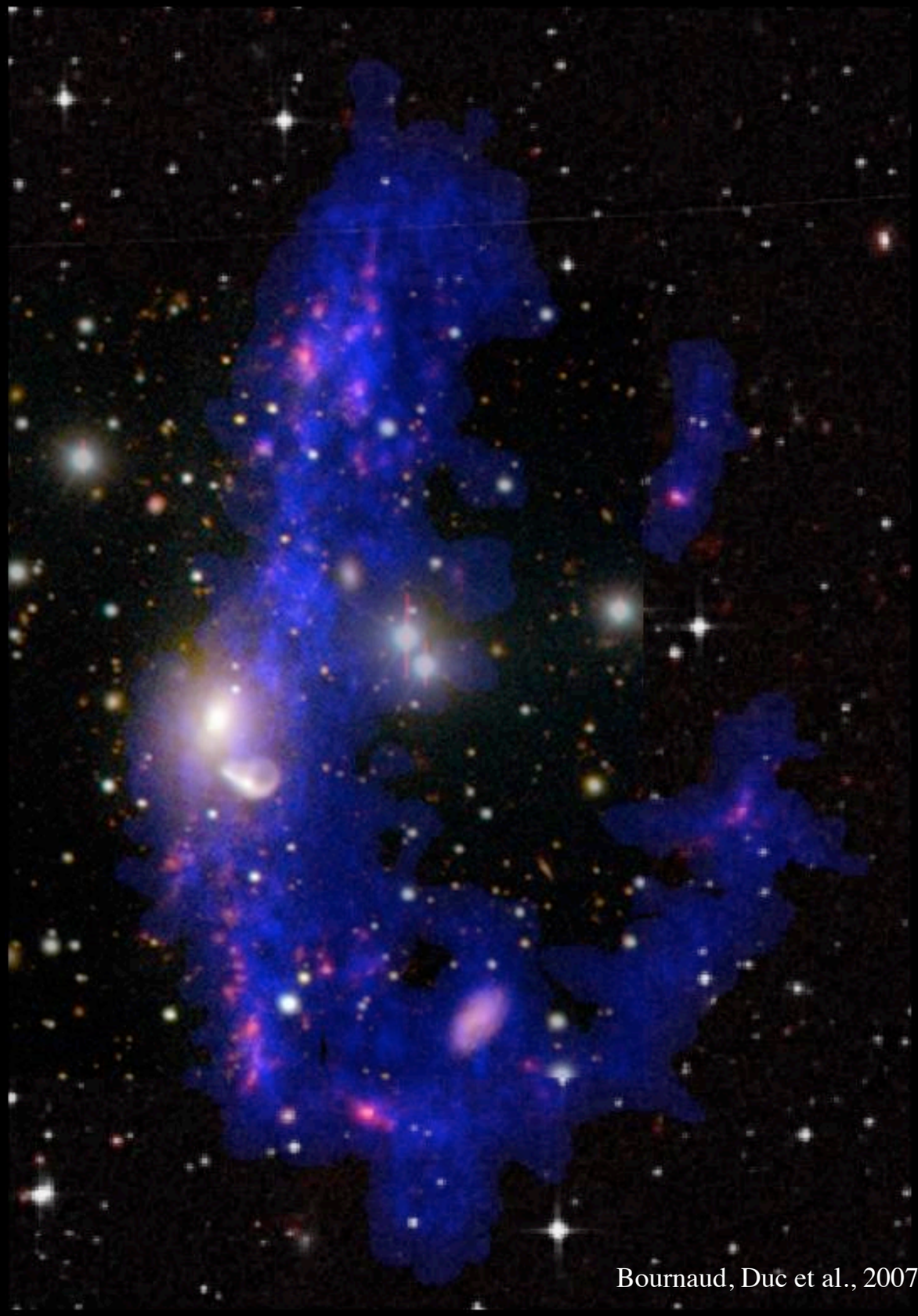
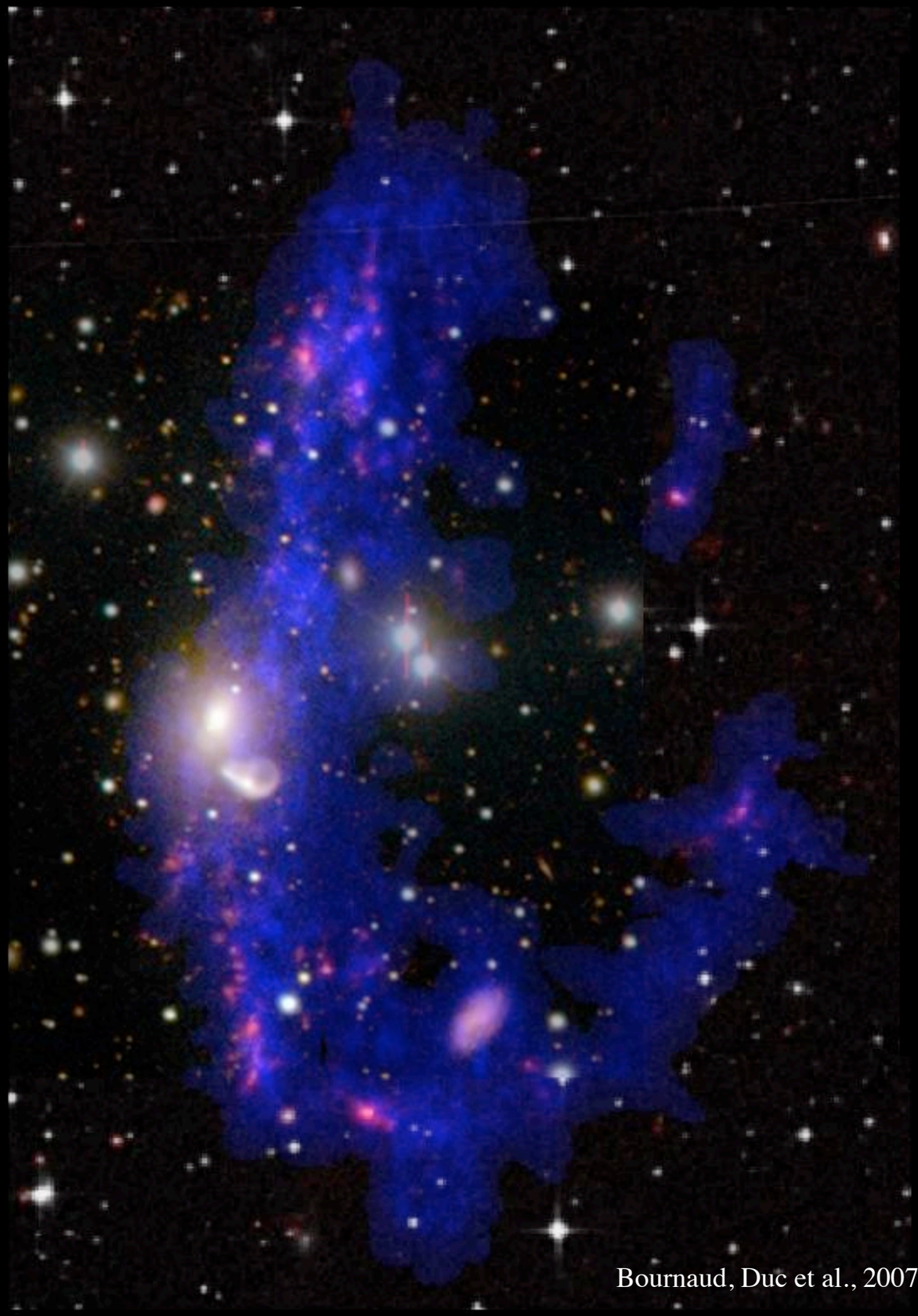
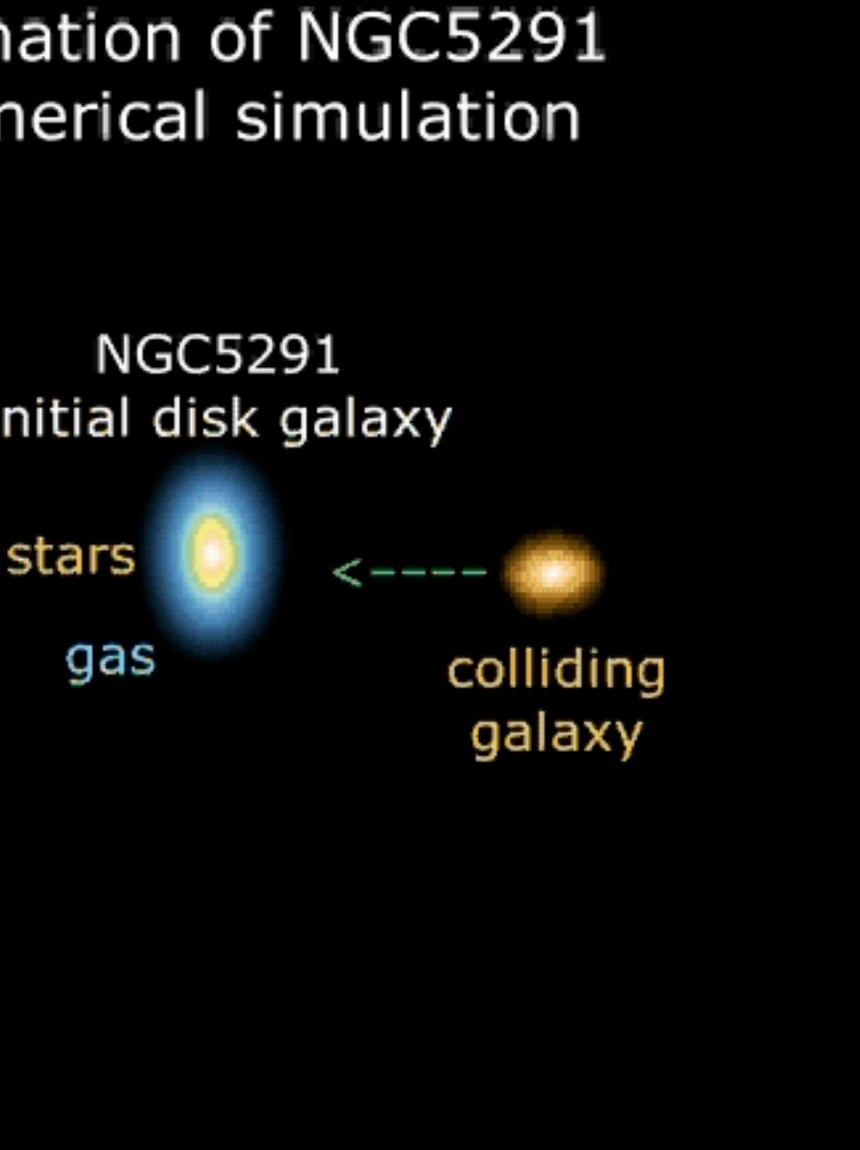


Bournaud, Duc et al., 2007

Measuring the dynamical mass of collisional debris

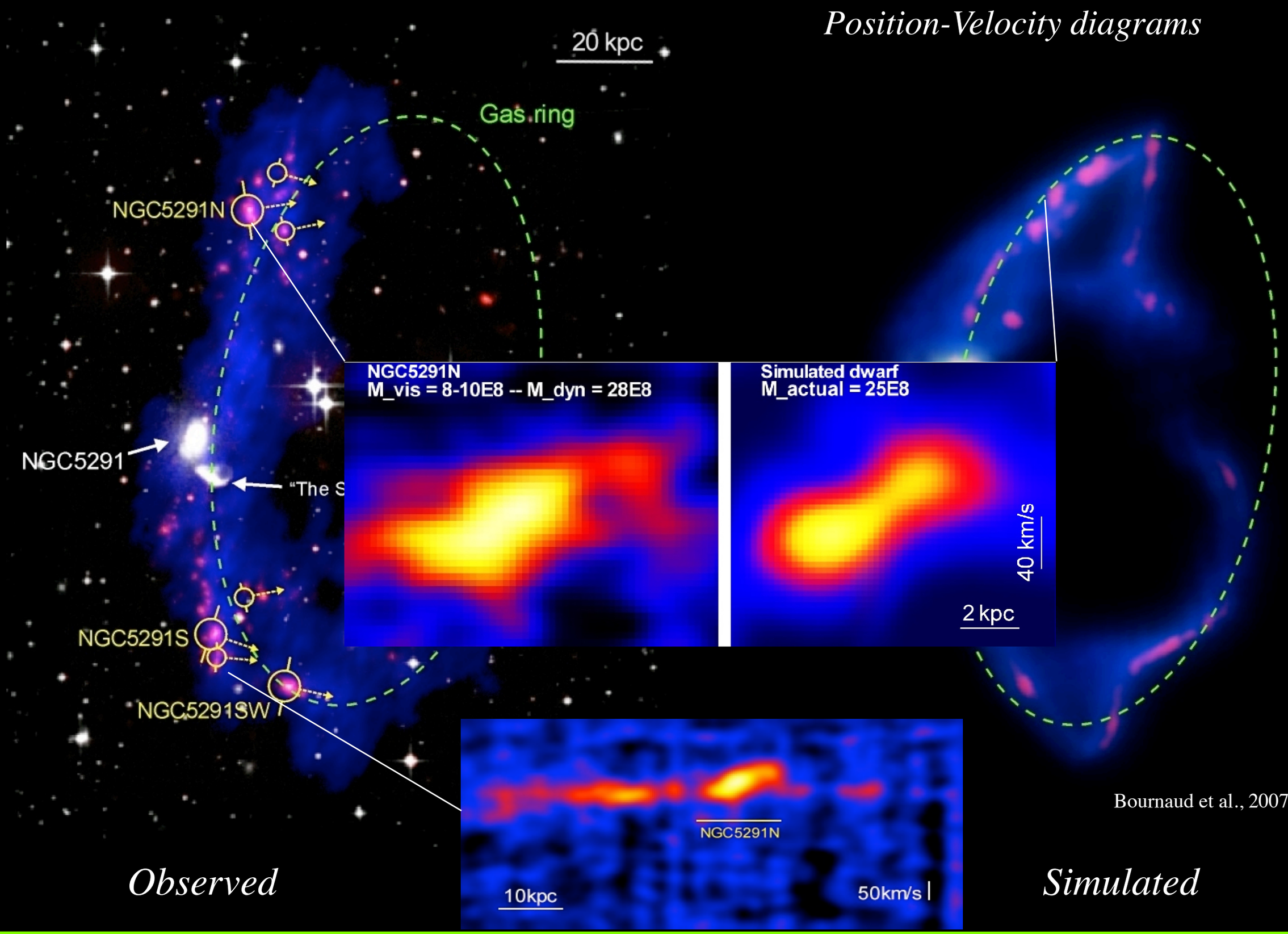


Bournaud, Duc et al., 2007



Measuring the dynamical mass of collisional debris

Position-Velocity diagrams

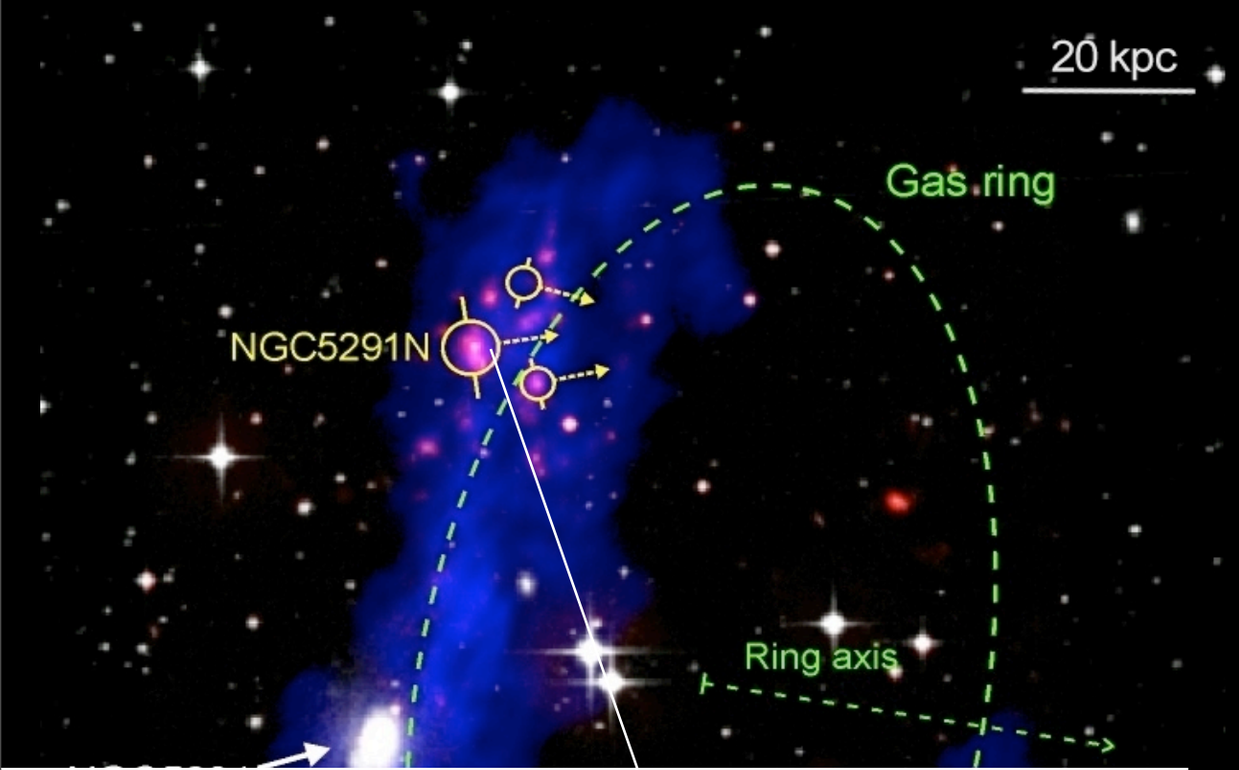


Bournaud et al., 2007

Observed

Simulated

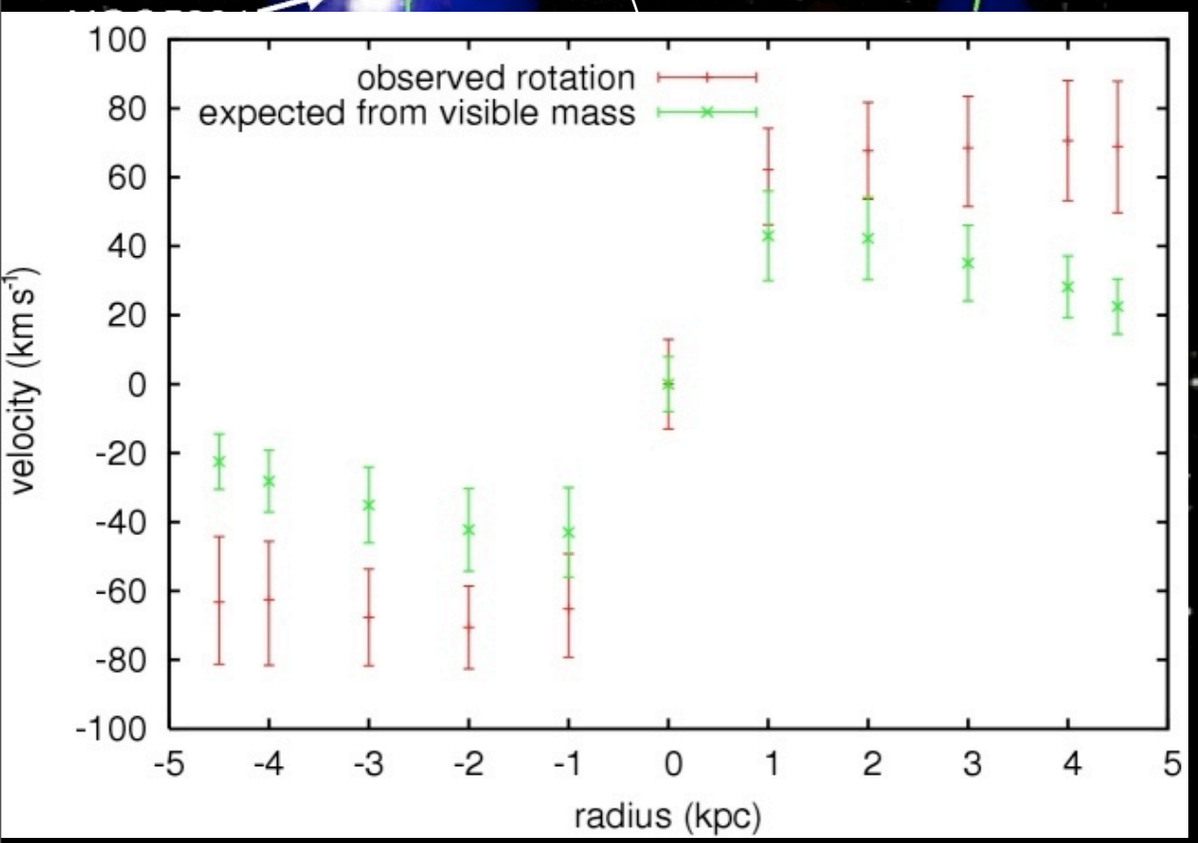
Measuring the dynamical mass of collisional debris



$$M_{lum} = M_{HI} + M_{H2/CO} + M_{stars}$$

$$M_{dyn} = 3 \times M_{lum}$$

Evidence for missing mass



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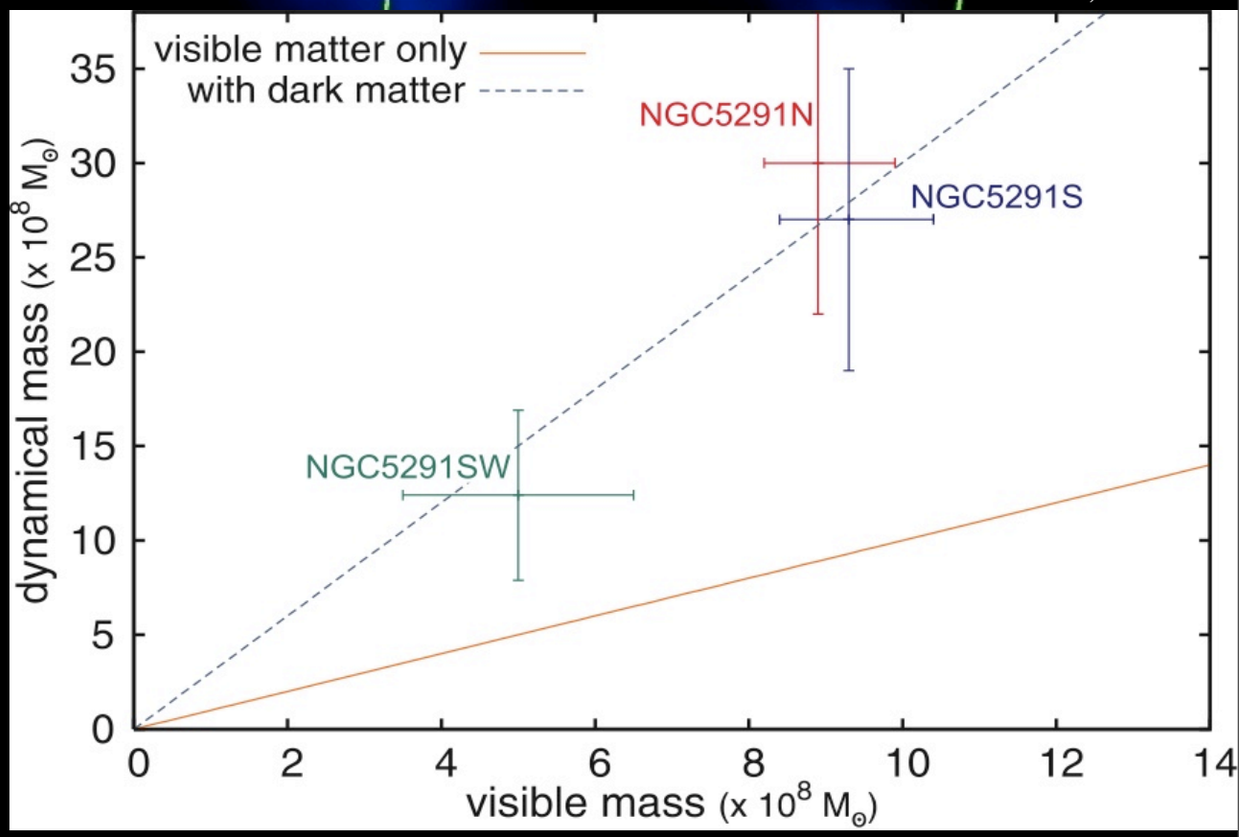
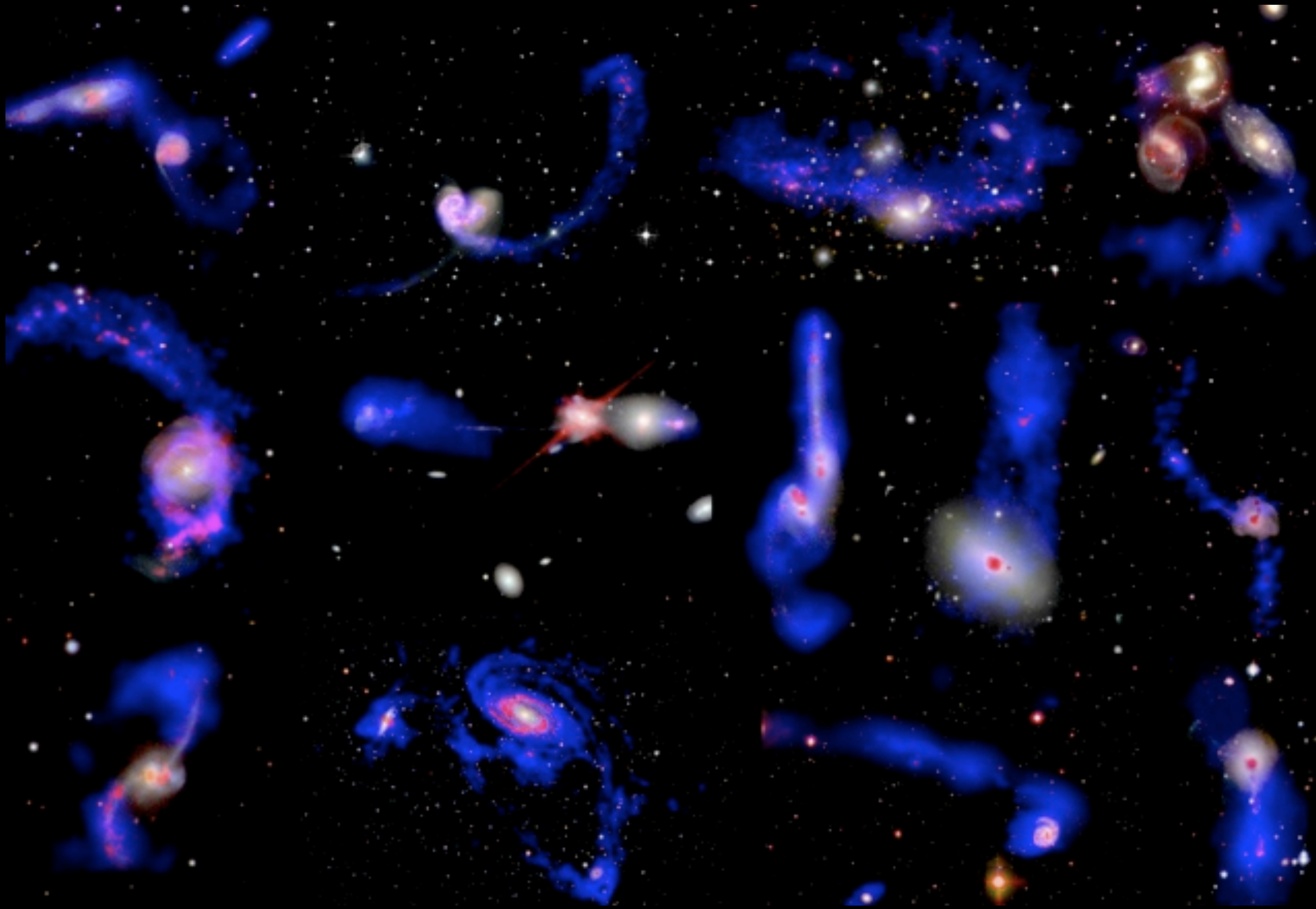


Missing mass in Tidal Dwarf Galaxies



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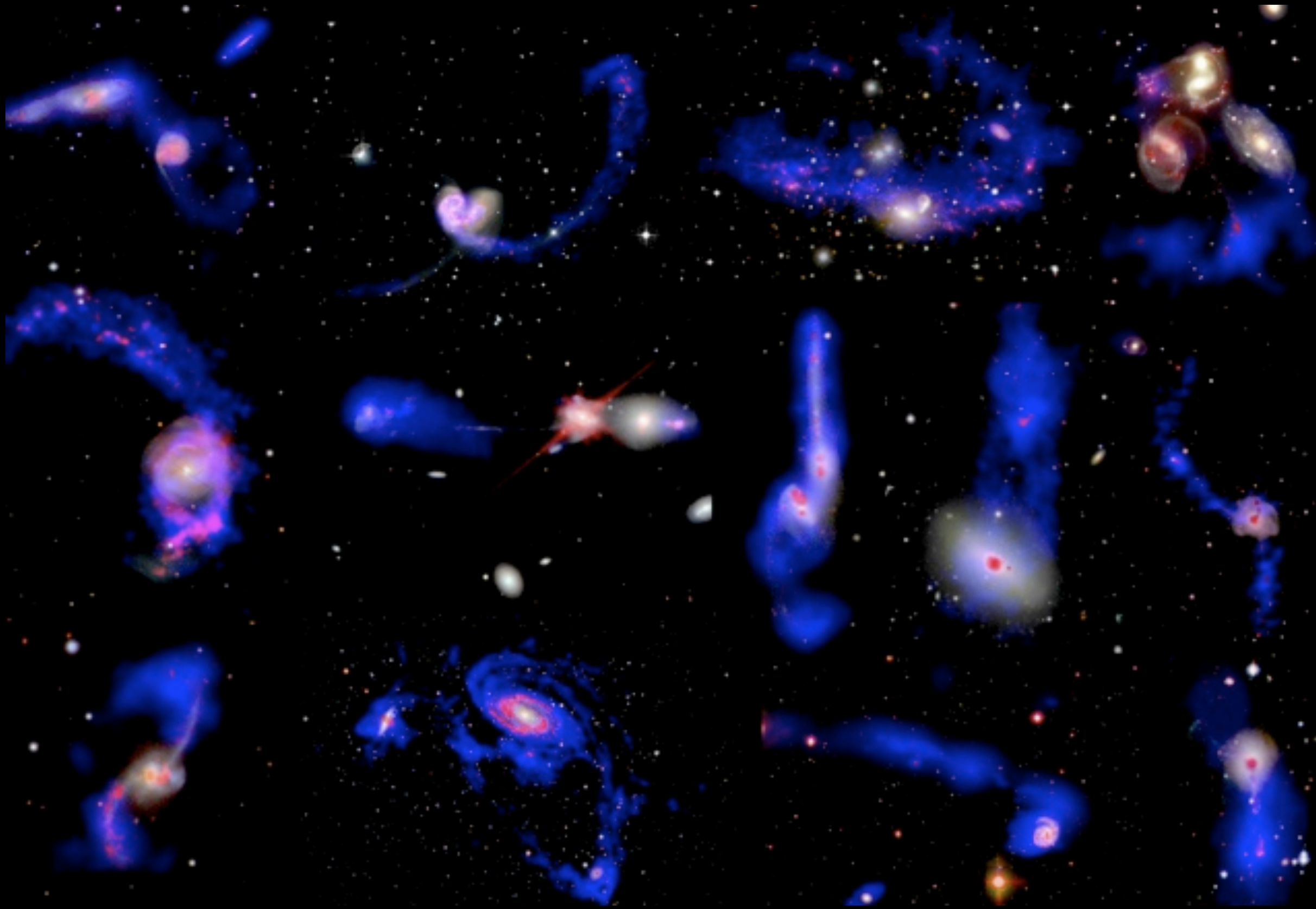

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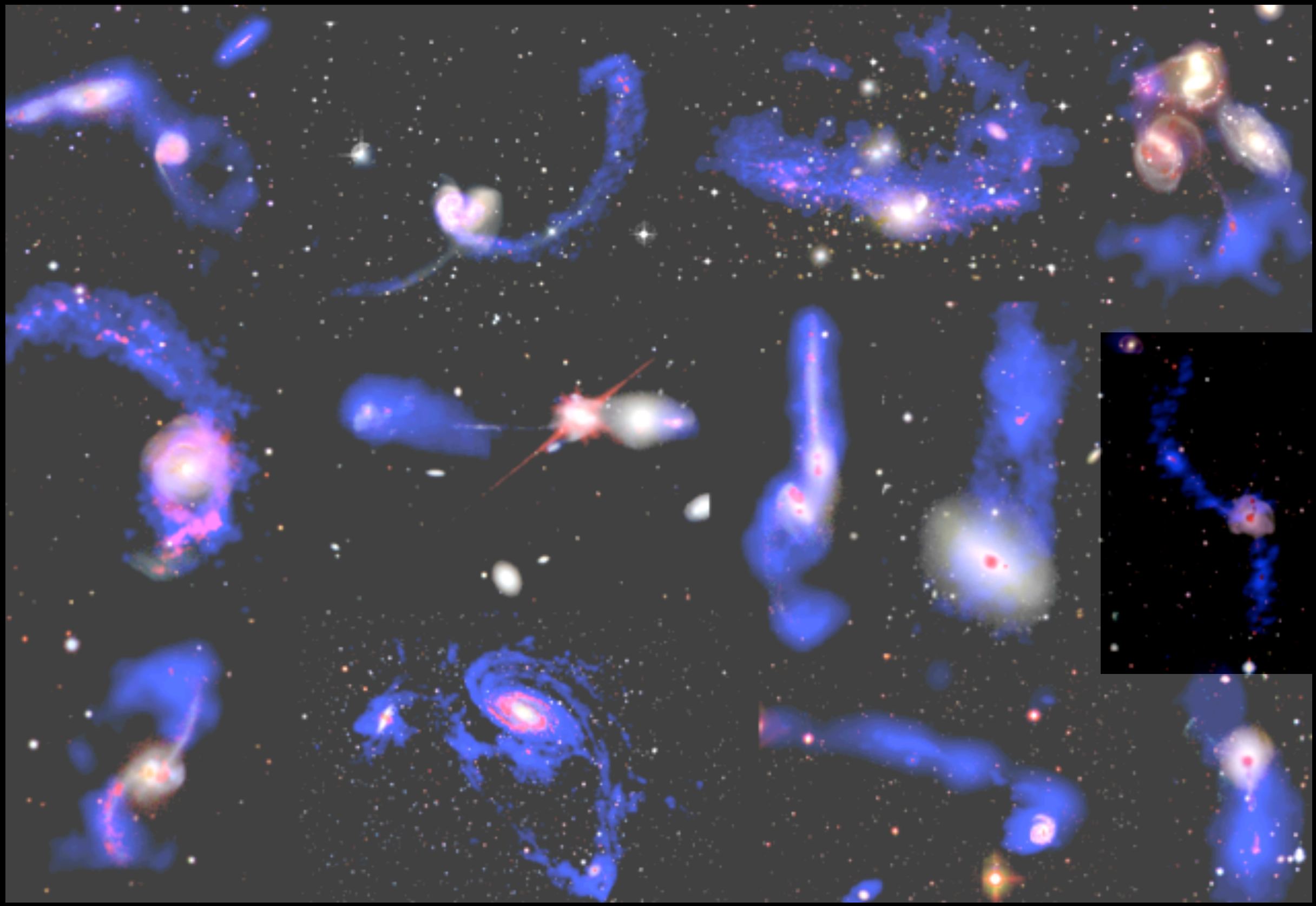
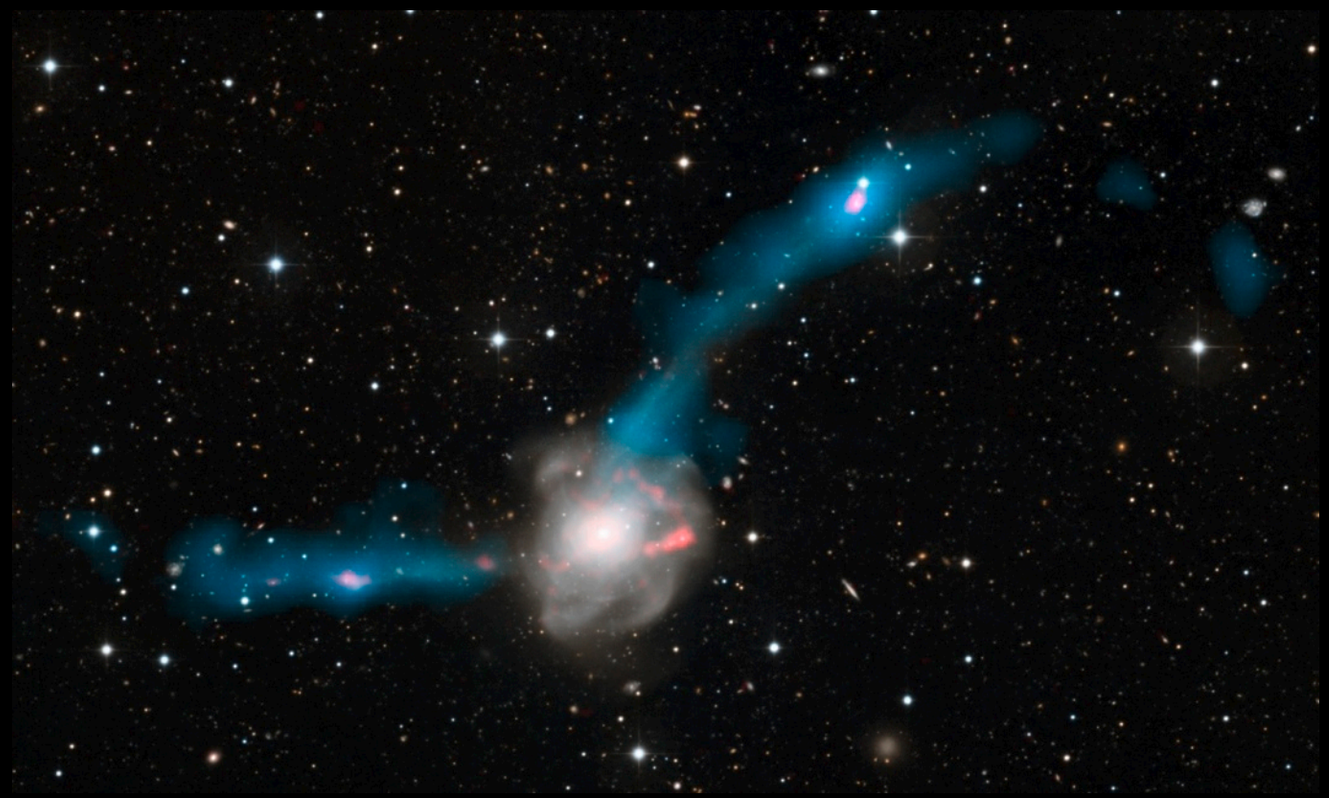


Missing mass in Tidal Dwarf Galaxies

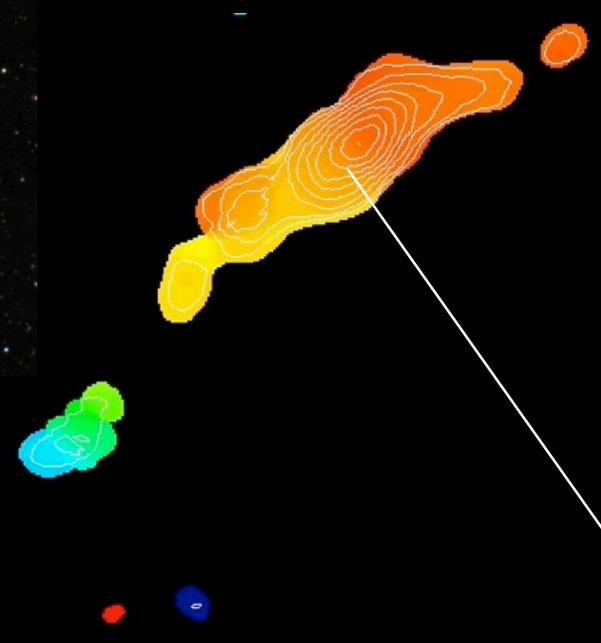
NGC 7252

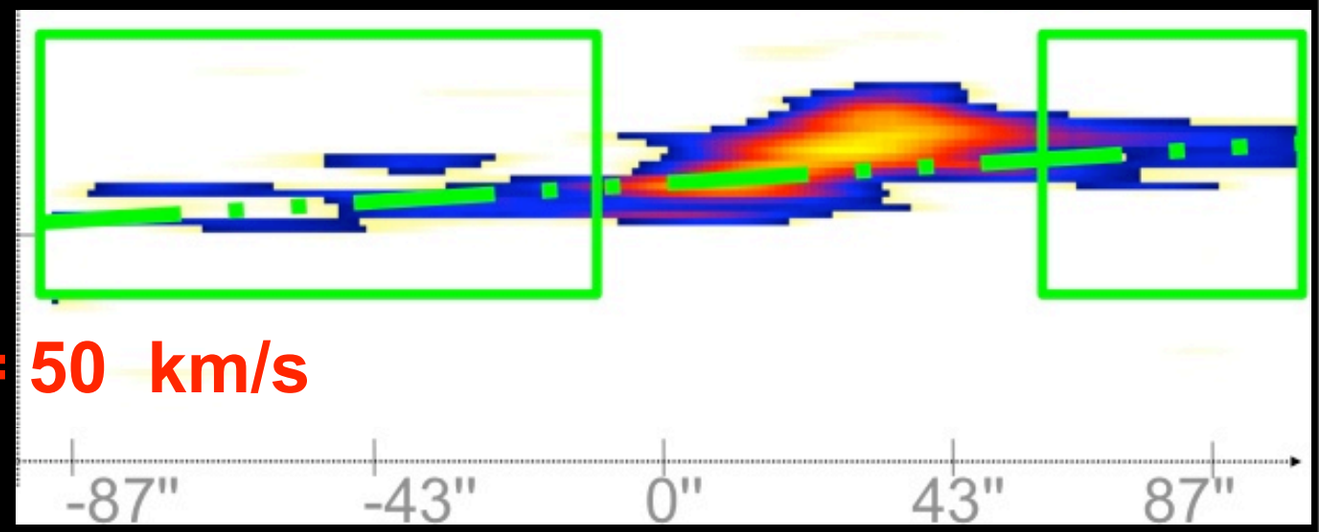
Missing mass in Tidal Dwarf Galaxies



Belles et al., 2011

NGC 7252





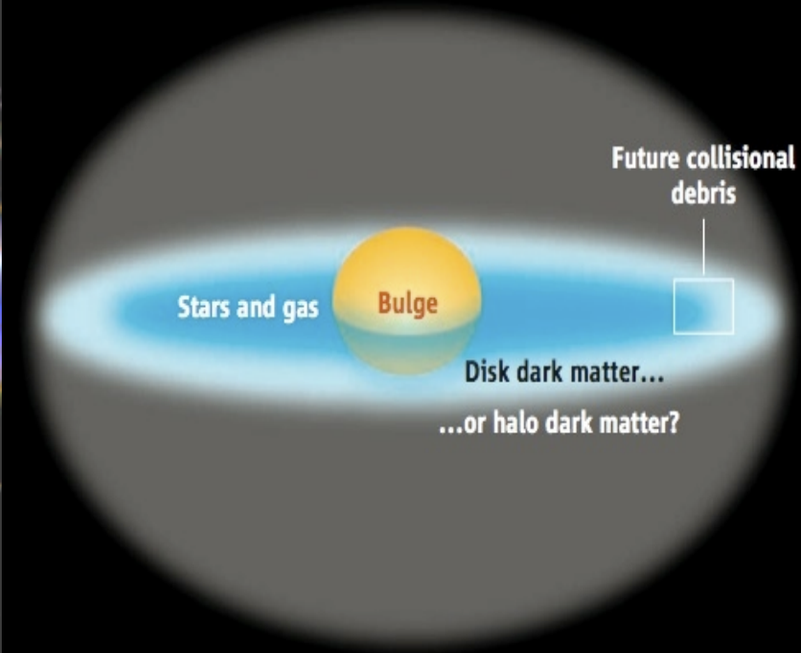
Δv = 50 km/s

=> M_{dyn} ~ 3.7 10^9 Mo = 2.6 x M_{HI}

Origin of the missing mass

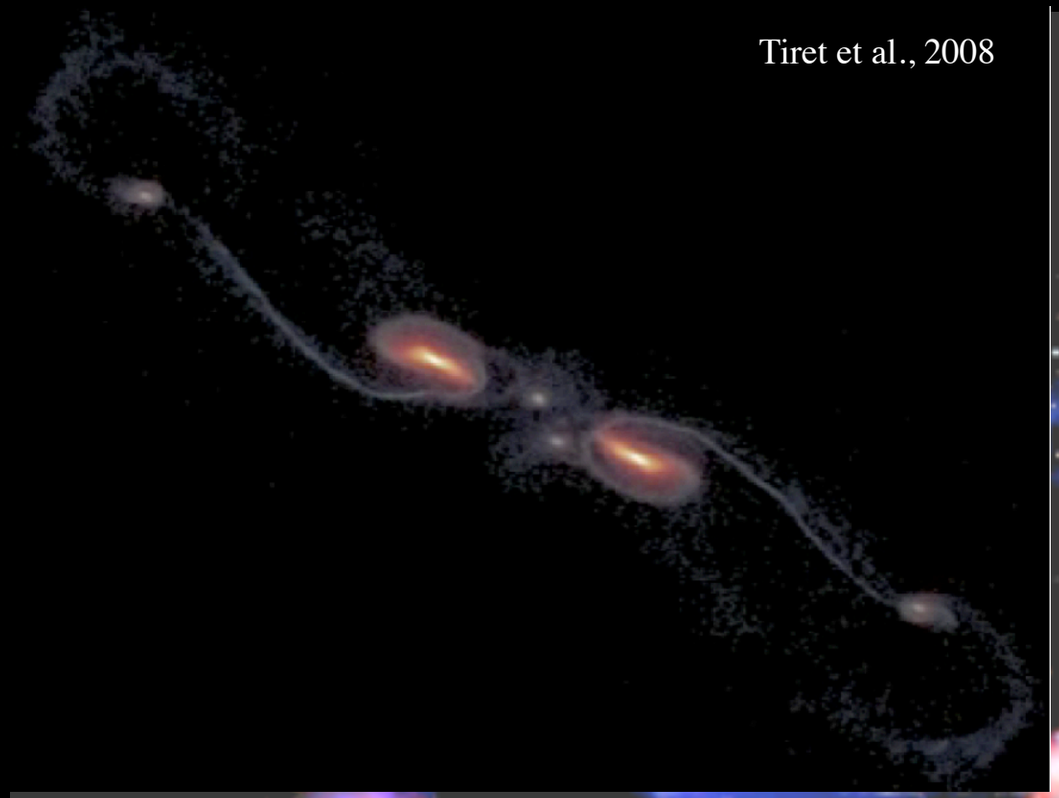
In spiral disks! Less than 10% comes from the cosmological halo: not conventional DM

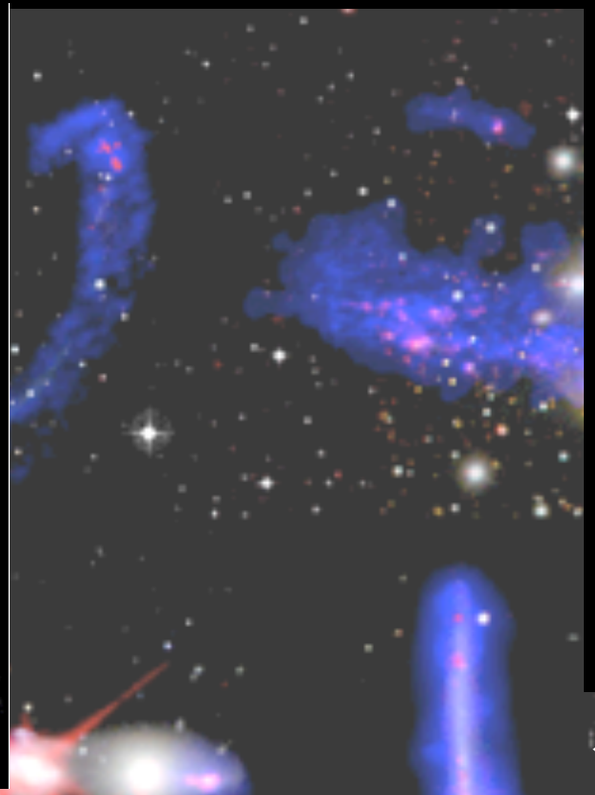
TDGs are dark-matter poor objects

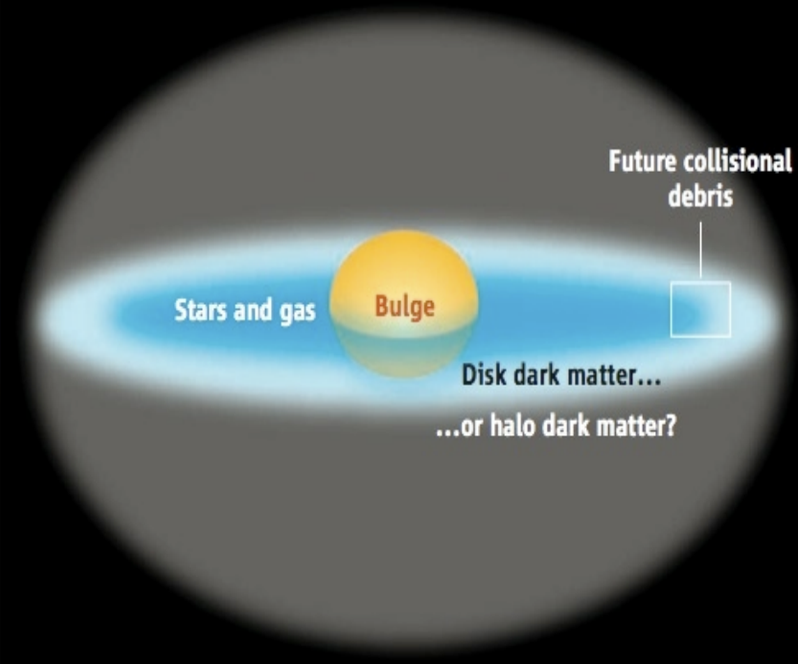


Origin of the missing mass

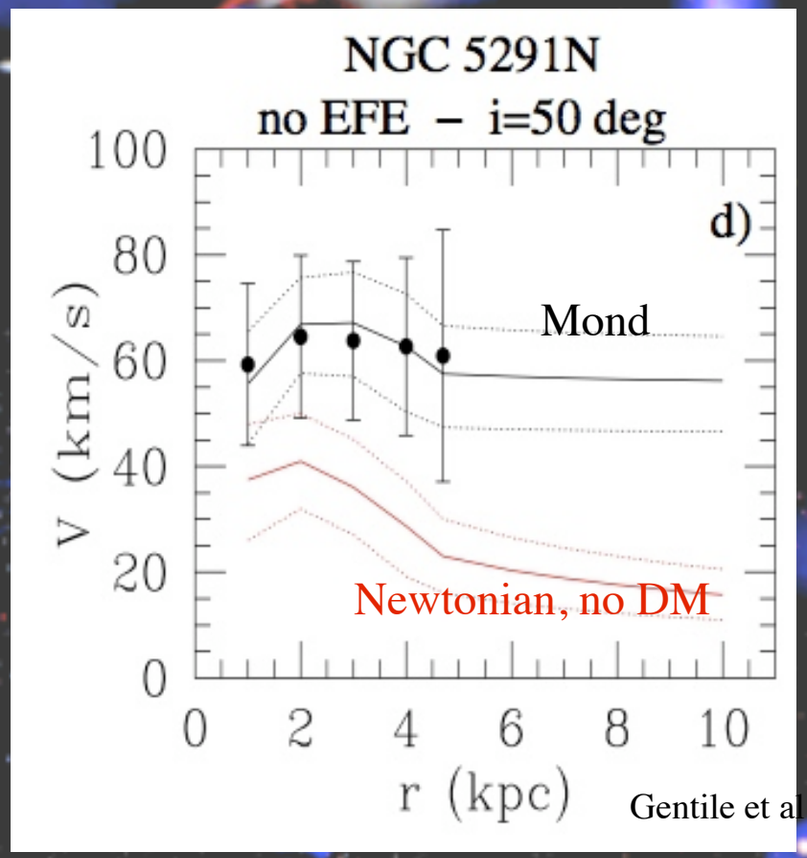
Tiret et al., 2008





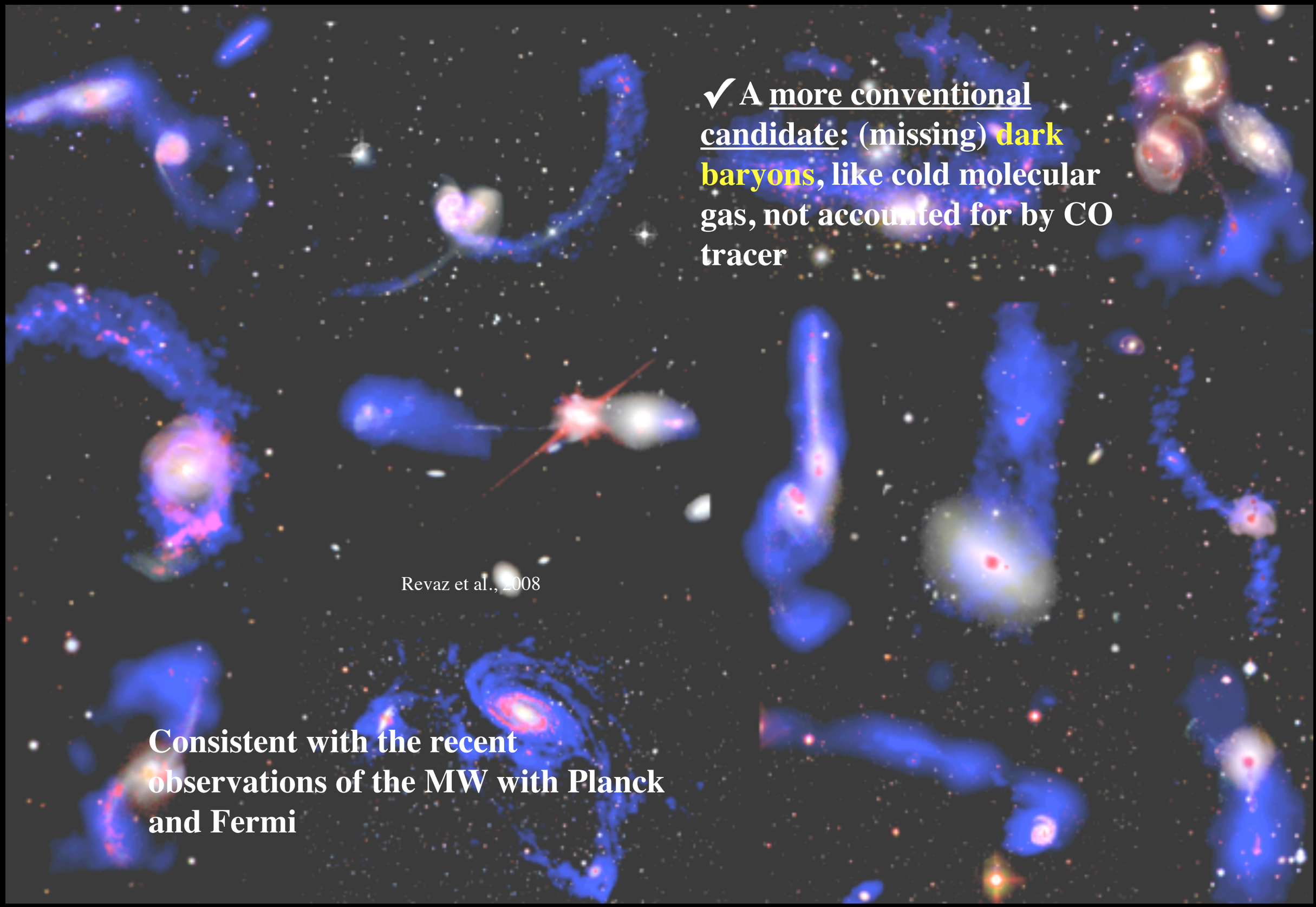


✓**Alternative theories:**
MOND may reproduce the formation of TDGs and their internal kinematics: Milgrom (2007), Gentile at al. (2007)
See TDG Bonn conference, 2009



Gentile et al., 2007

Origin of the missing mass



✓A more conventional candidate: (missing) dark baryons, like cold molecular gas, not accounted for by CO tracer

Revaz et al., 2008

Consistent with the recent observations of the MW with Planck and Fermi

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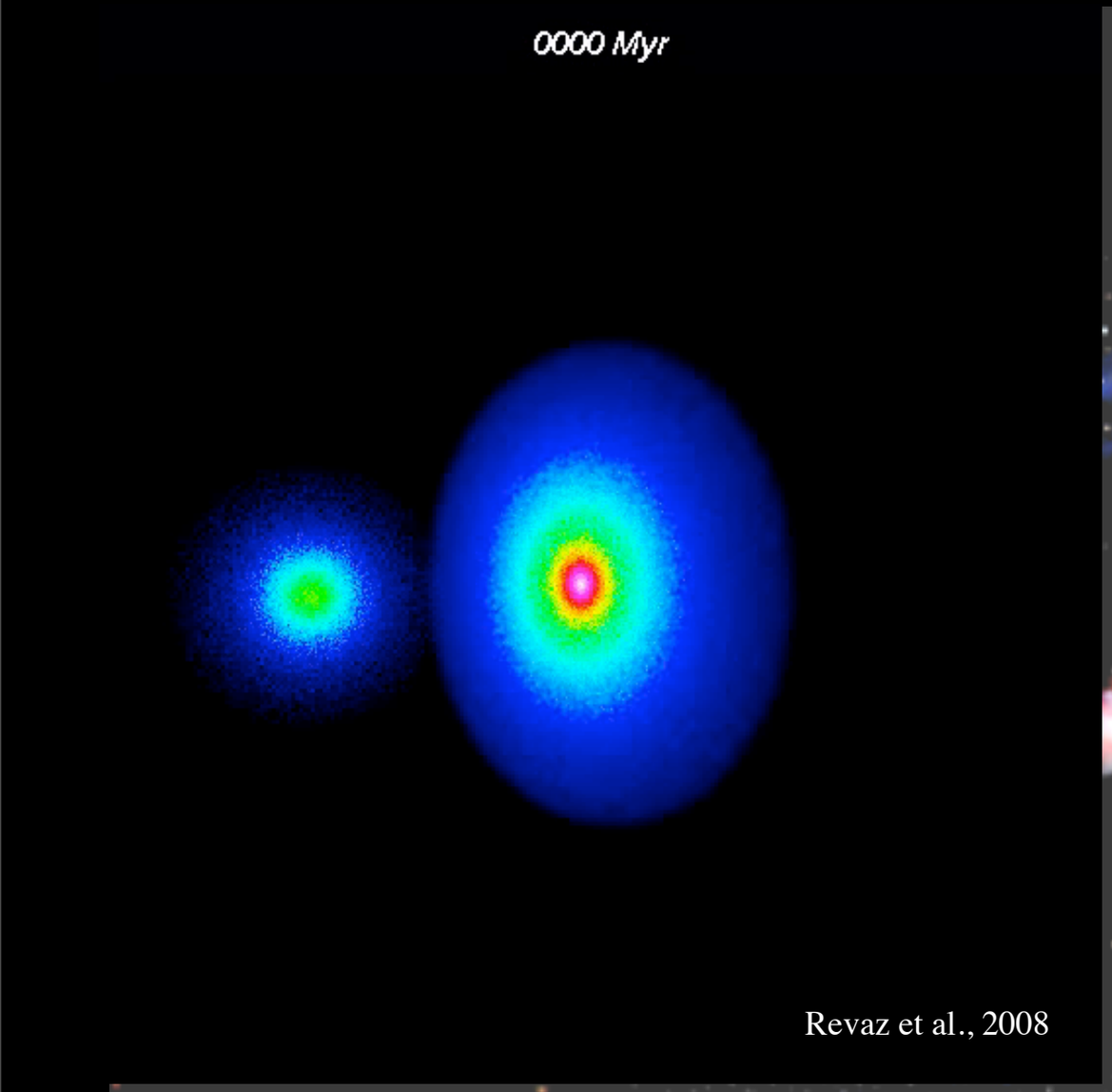

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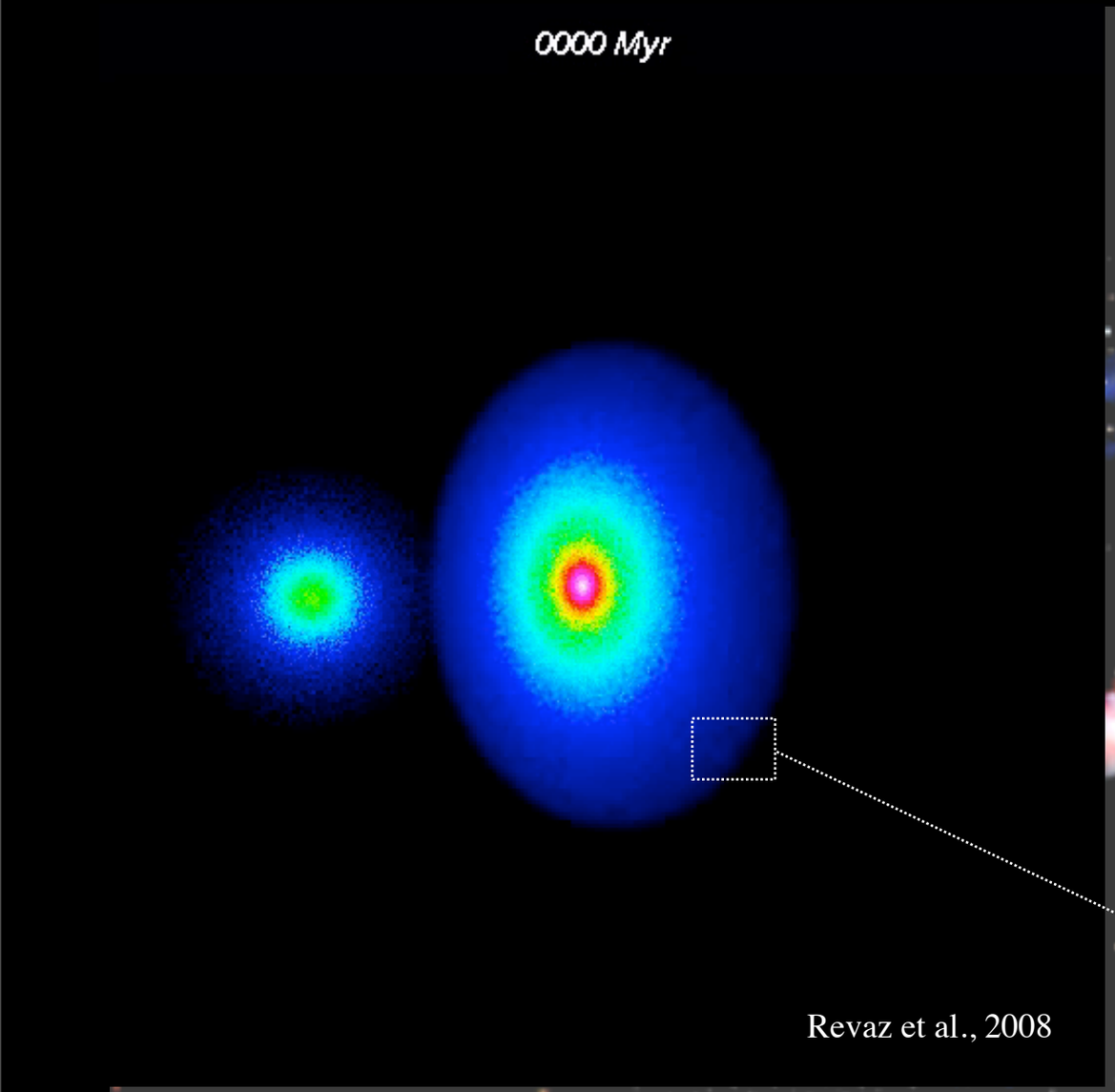

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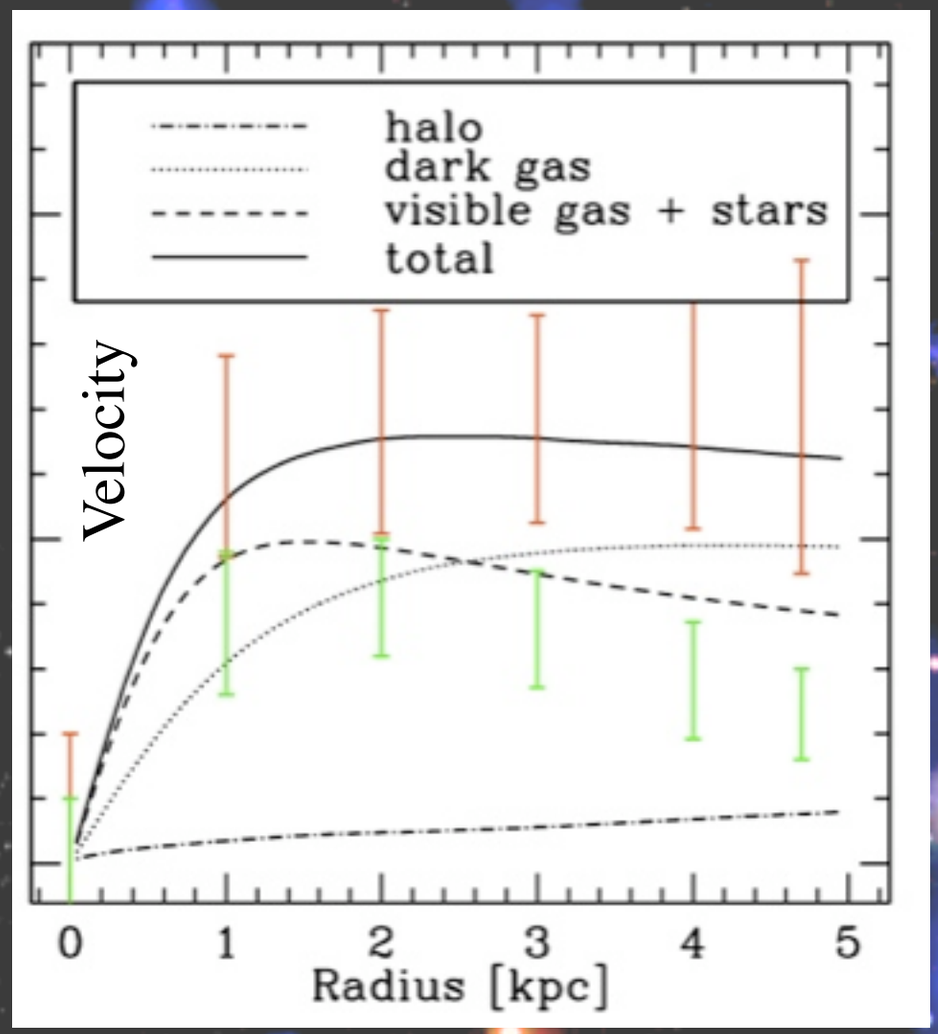
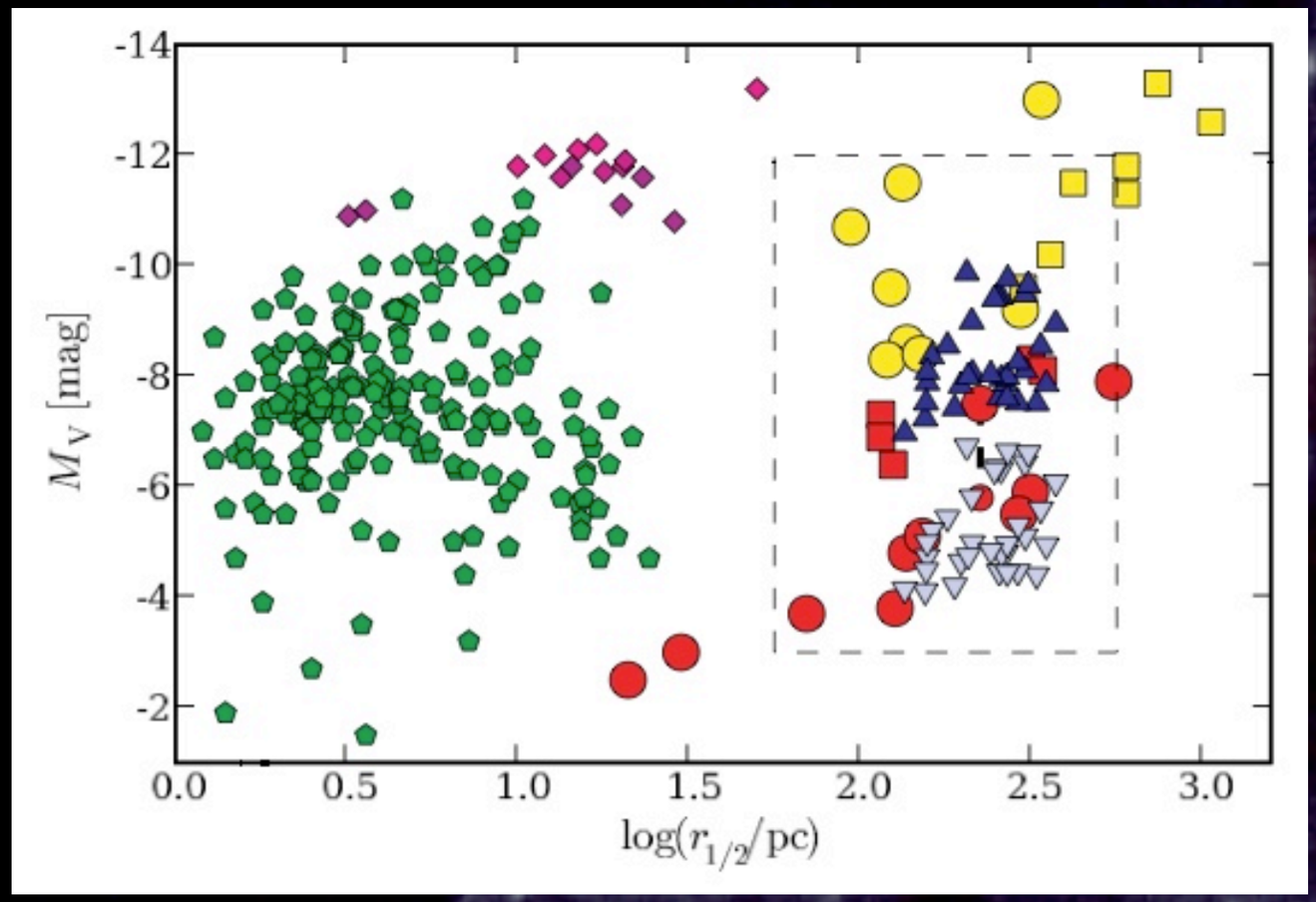


Consistent with the recent observations of the MW with Planck and Fermi

Survival of Tidal Dwarf Galaxies

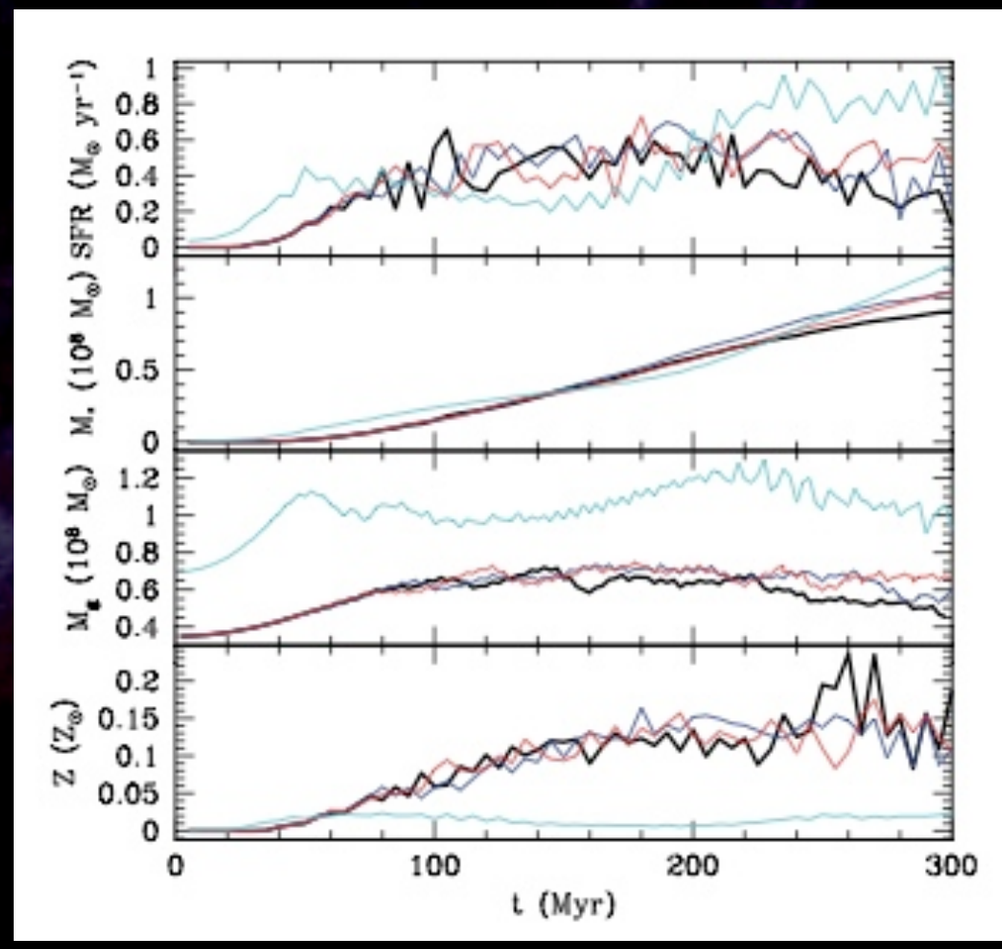
How do DM poor galaxies evolve?

- Structural parameters of evolved DM poor satellites



Metz & Kroupa, 2007

- Chemical enrichment (Recchi et al. 07)



Survival of Tidal Dwarf Galaxies: in the real world

- *Mostly young TDGs have yet been unambiguously identified*

- *Numerical simulations predict that a fraction of them should survive as satellite galaxies*

- *The observational quest for old TDGs still on going*

- *Several criteria to be met* simultaneously:

Searching for long-lived Tidal Dwarf Galaxies

• *Mostly young TDGs have yet been unambiguously identified*

• *Numerical simulations predict that a fraction of them should survive as satellite galaxies*

• *The observational quest for old TDGs still on going*

• *Several criteria to be met* simultaneously:

✓Structural diagnostic: low dark matter content

Method:
kinematical measurements:
• width of CO lines
• rotational curves (HI,Halpha)
• stellar velocity dispersion

✓Location: look for TDGs in favorable environments:
groups, cluster of galaxies, vicinity of early type galaxies
(preferentially along their equatorial plane)

✓Paternity test: measure of an excess of heavy elements, inherited from their parent galaxies

Method:
• measure of oxygen abundance in the ionized gas
• detection of molecular gas
• measure of the metallicity of stellar populations

Searching for long-lived Tidal Dwarf Galaxies

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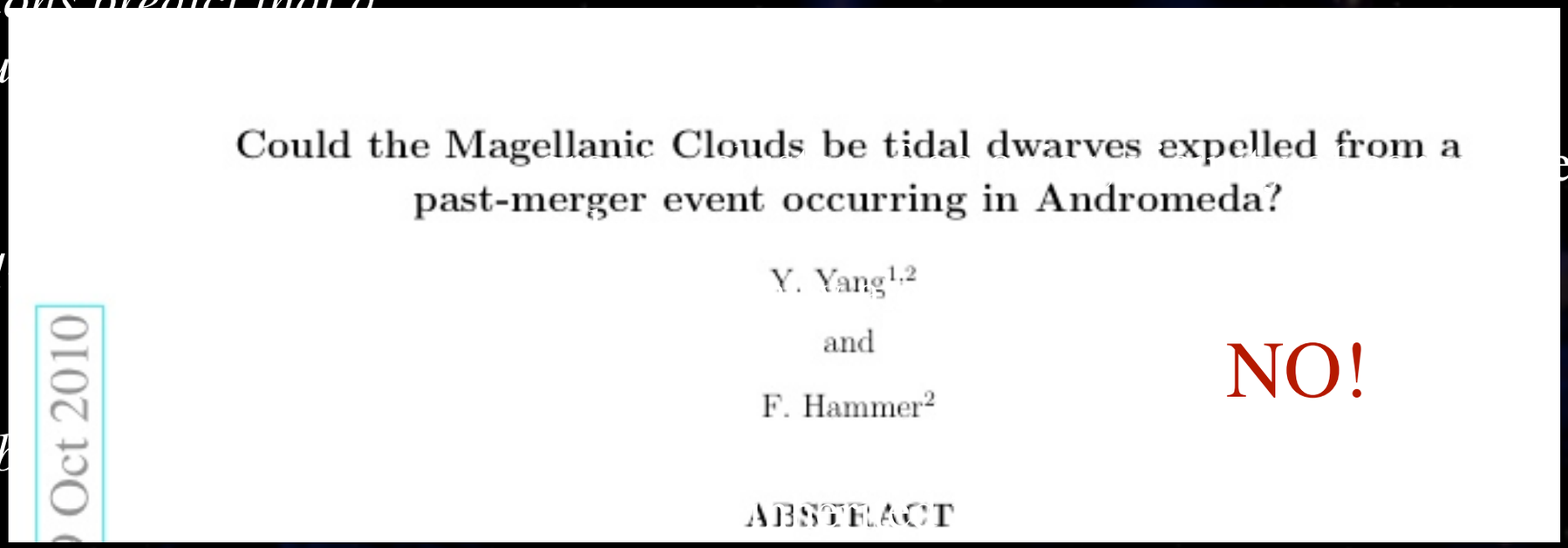


Could the Magellanic Clouds be tidal dwarves expelled from a past-merger event occurring in Andromeda?

Y. Yang[1,2]

and

F. Hammer[2]

ABSTRACT

NO!

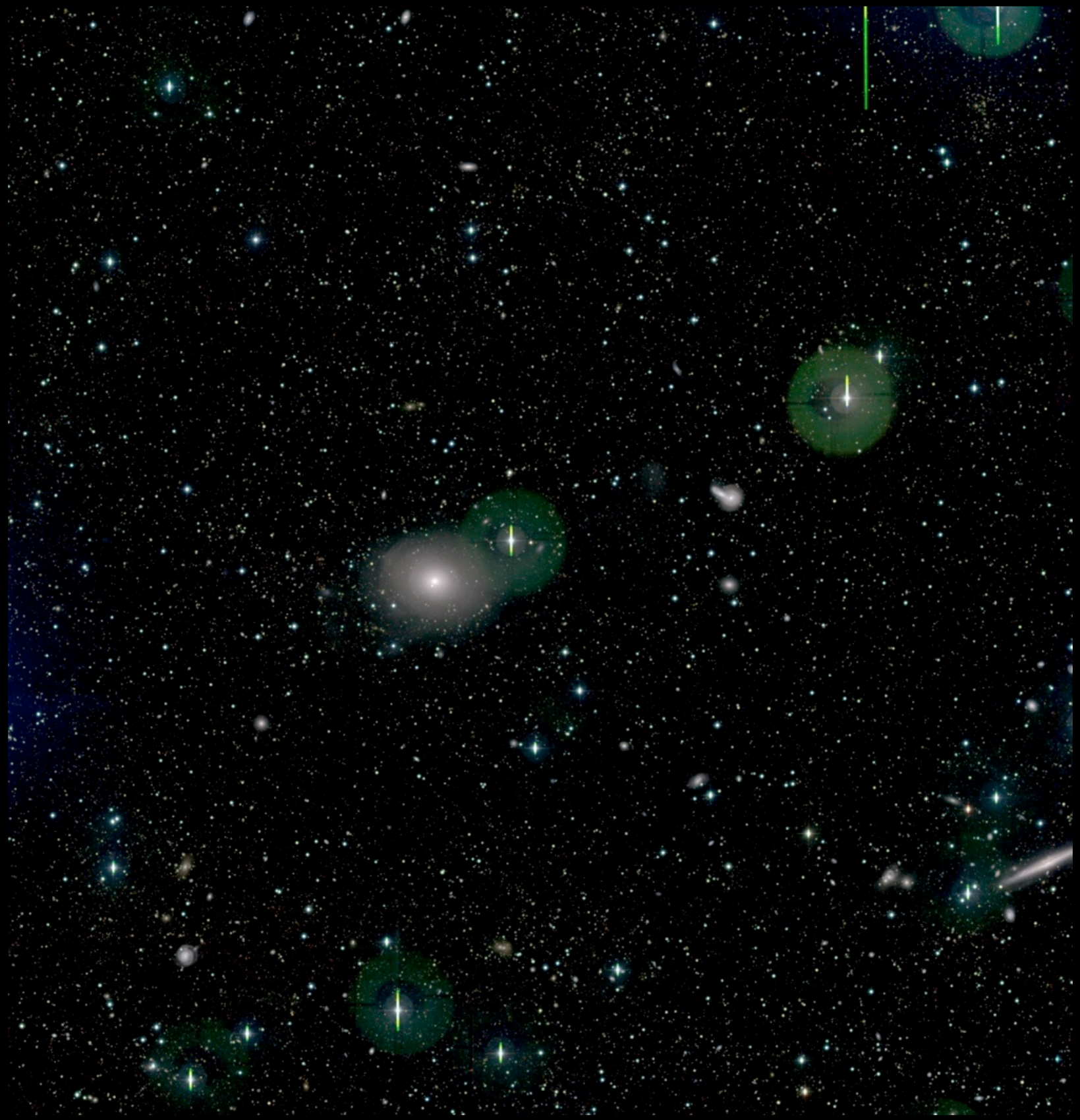
Method:
- measure of oxygen abundance in the ionized gas
- detection of molecular gas
- measure of the metallicity of stellar populations

Cases of 0.5-1 Gyr old Tidal Dwarf Galaxies

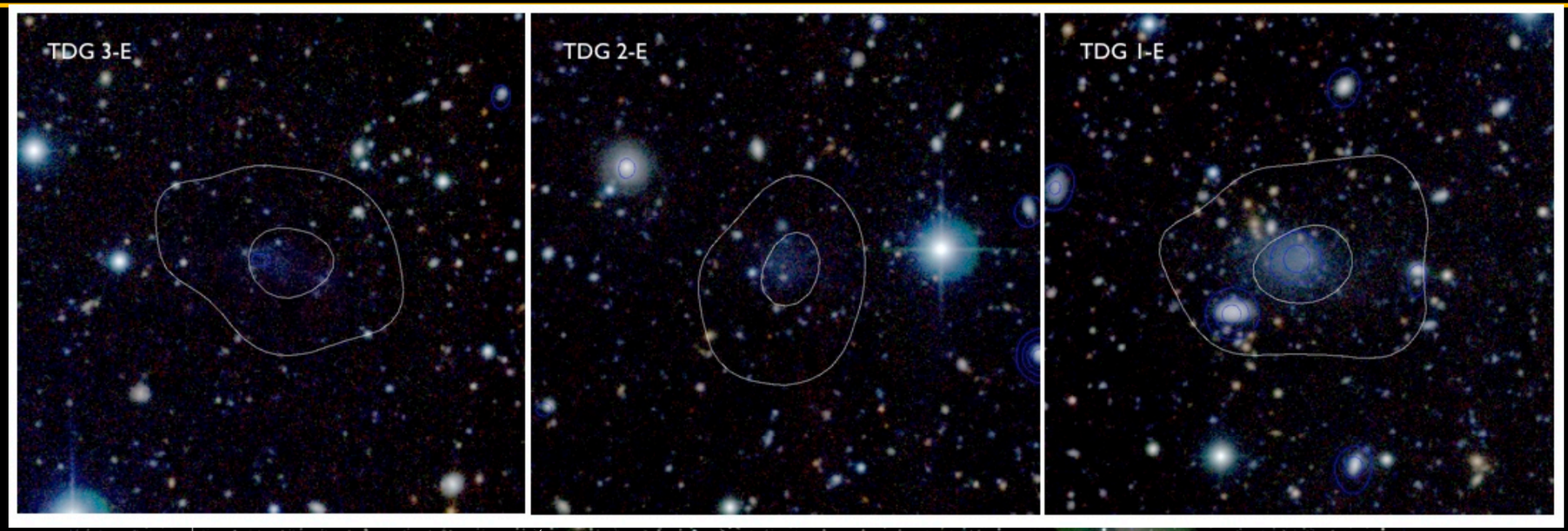
TDGs with age > 500 Myr located near old relaxed mergers

Case of 2-3 Gyr old Tidal Dwarf Galaxies

NGC 5557



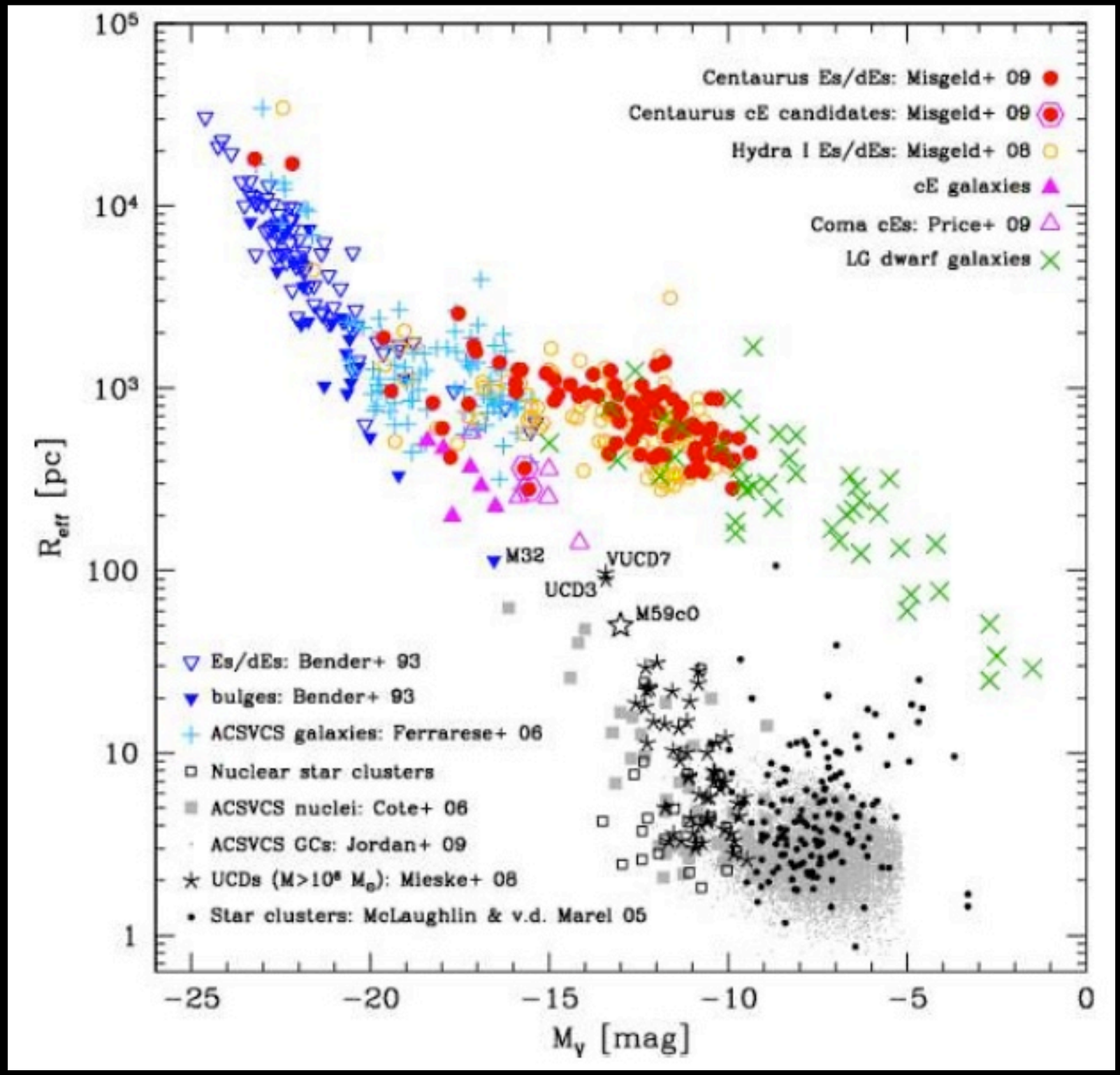
Case of 2-3 Gyr old Tidal Dwarf Galaxies



Case of 2-3 Gyr old Tidal Dwarf Galaxies

Duc, & Atlas-3D team, 2010

and the TDGs in this diagram ???



Misgeld & Hilker, 2011

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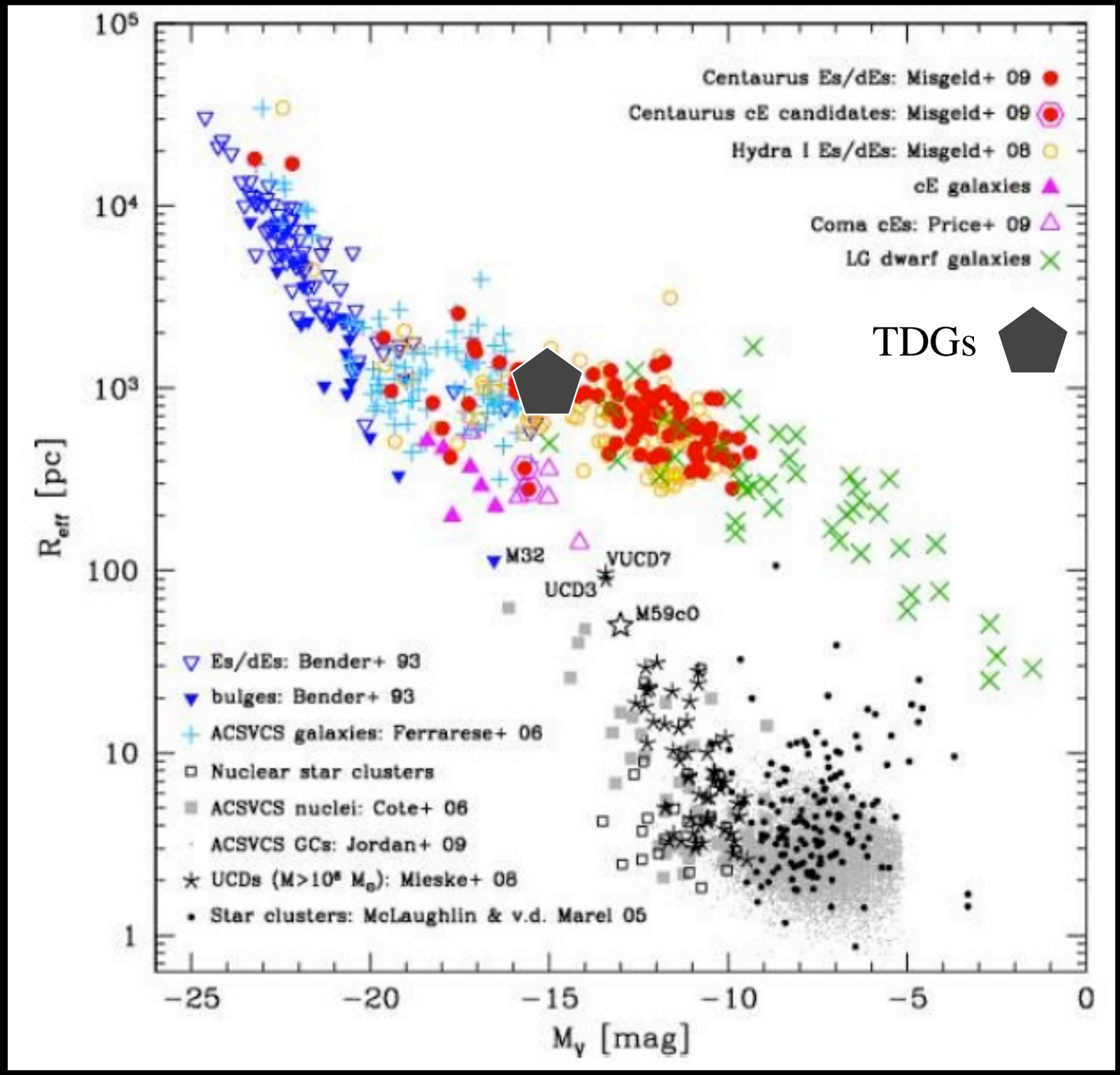
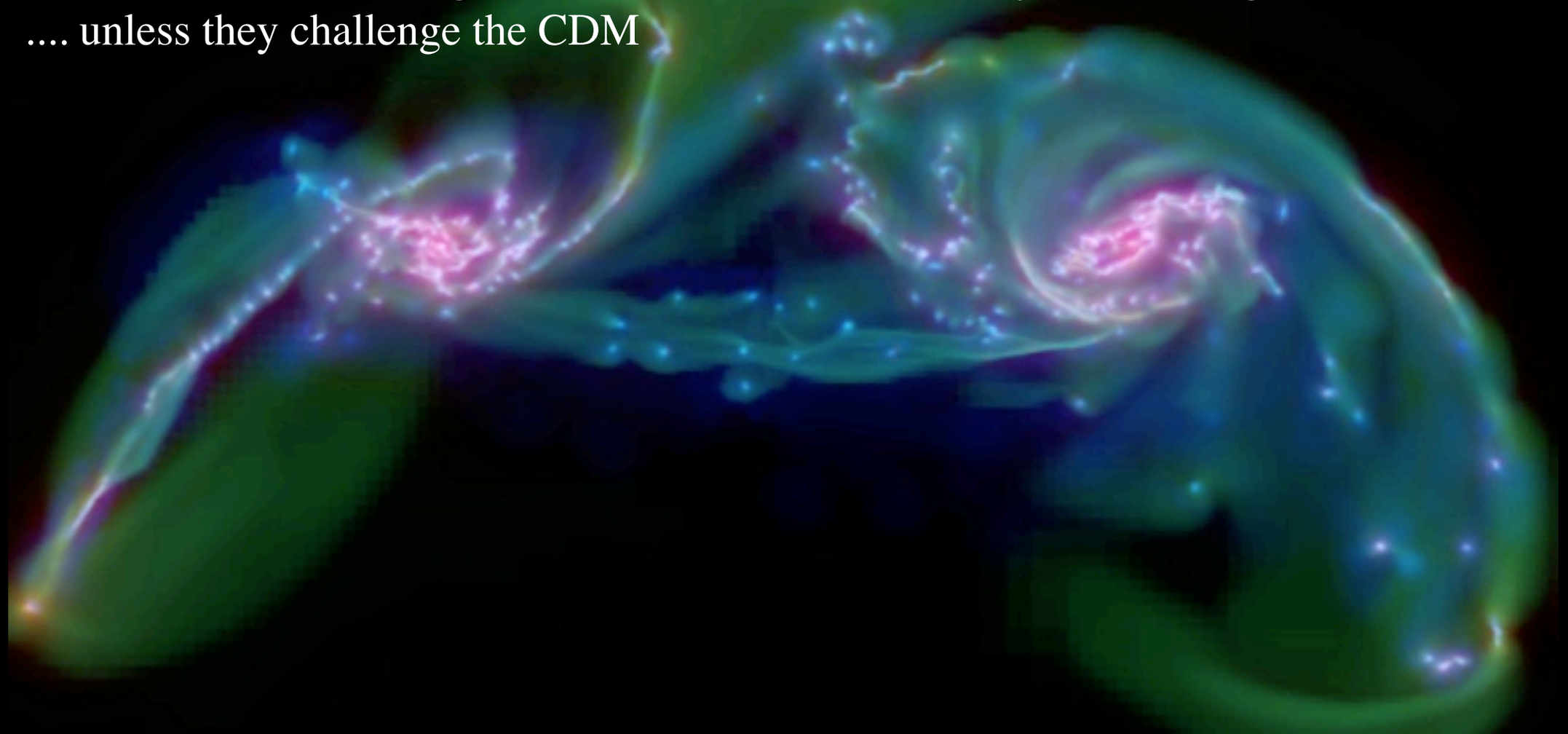


Misgeld & Hilker, 2011

Conclusions

TDGs are born in gas-rich mergers, together with SSCs
TDGs are rotating while SSCs are pressure supported
TDGs are formed early-on through a top-down process
TDGs do not contain cosmological dark matter but have a baryonic missing mass.
.... unless they challenge the CDM



TDGs are only produced in nearby mergers that meet specific conditions
TDGs may survive for several Gyrs
TDGs may be born much more efficiently in distant mergers

Teyssier et al., 2010