# Probing the mass assembly of galaxies with deep imaging

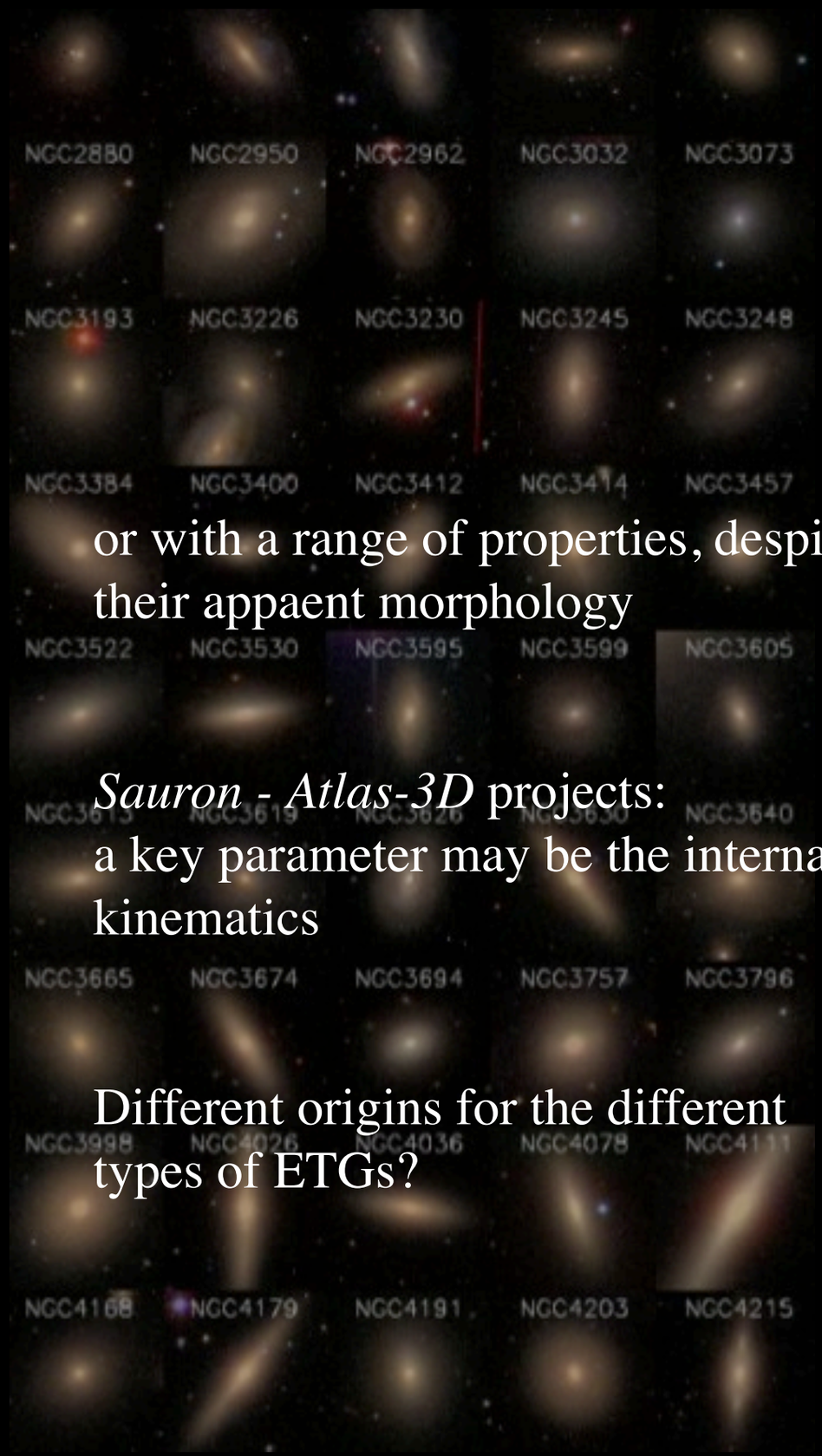
Atlas$^{3D}$ Collaboration
NGVS Collaboration

Pierre-Alain Duc, AIM, Paris-Saclay

# Early-type galaxies...


- For some, just *red and dead*

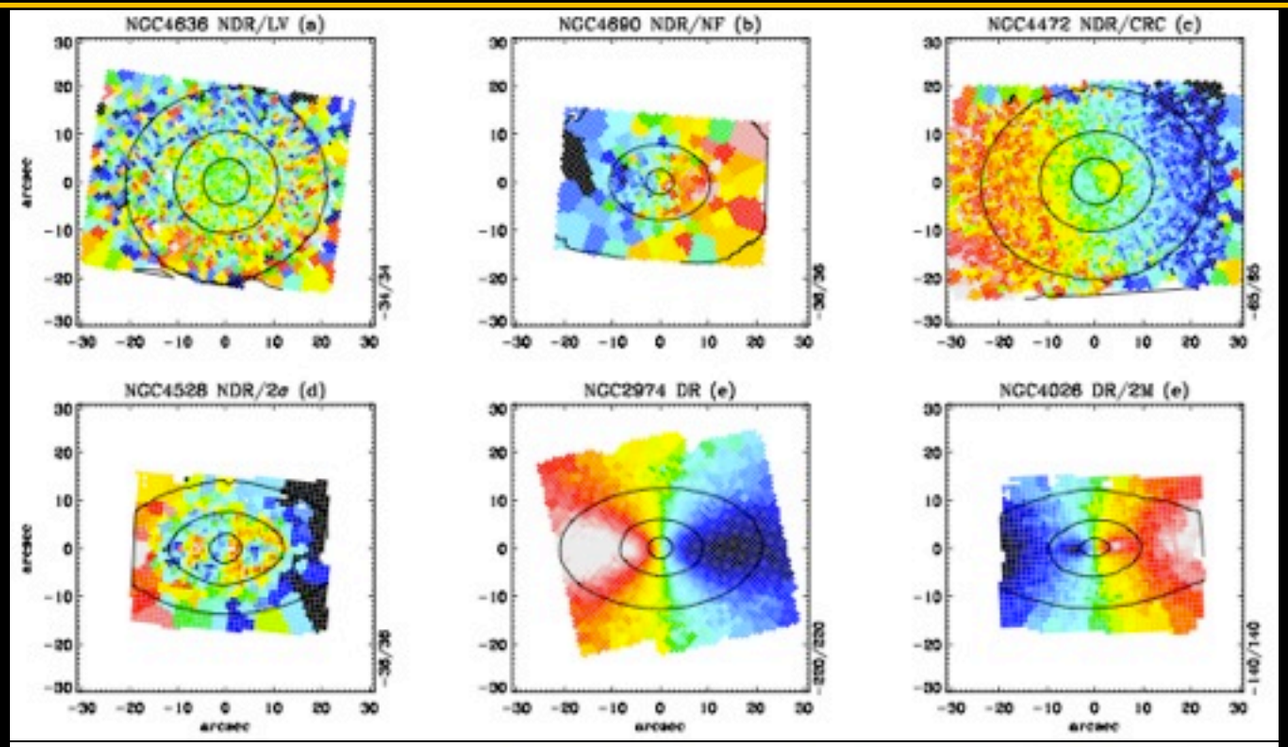
# Early-type galaxies...

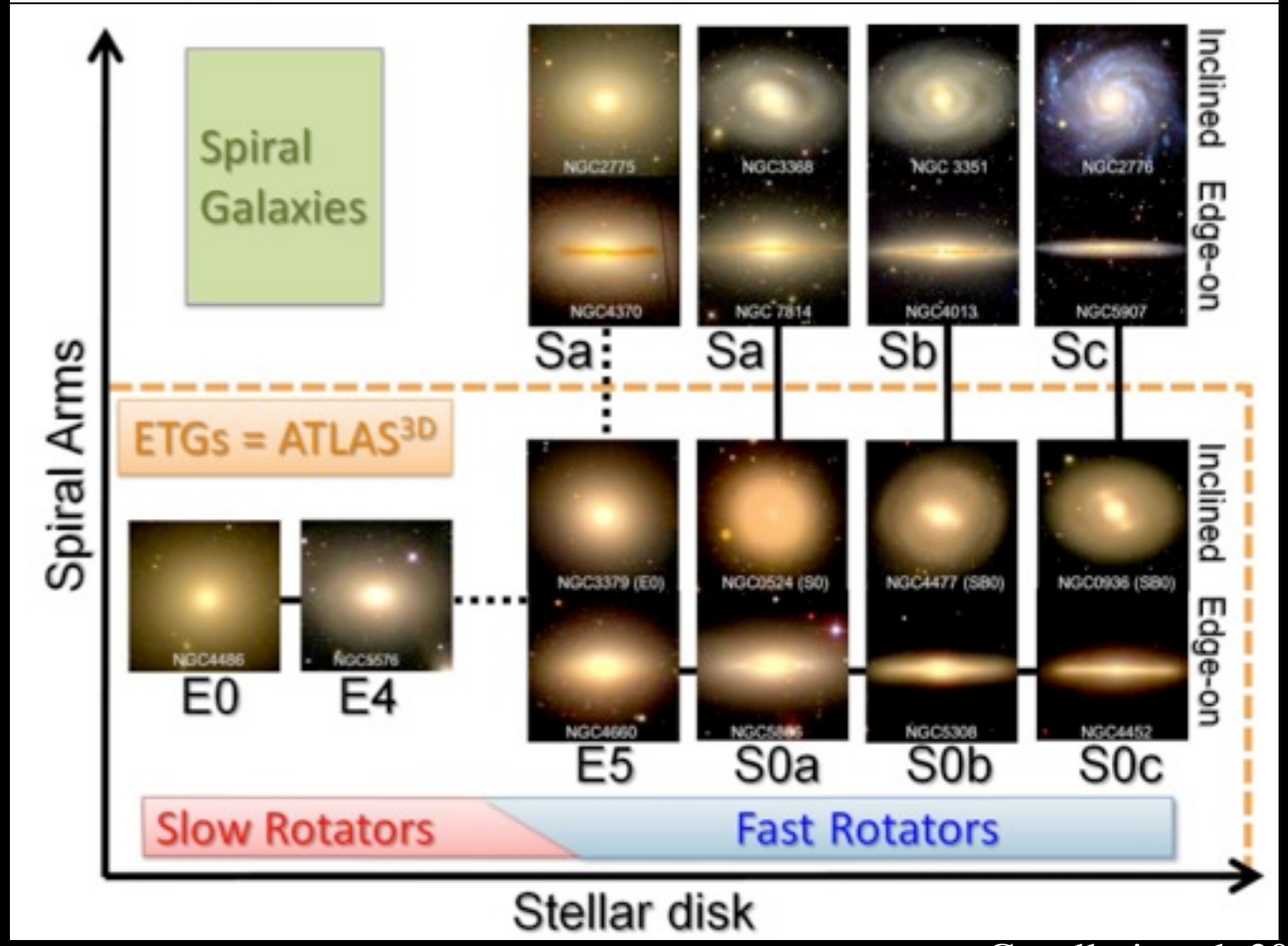



or with a range of properties, despite their appaent morphology

*Sauron - Atlas-3D* projects:
a key parameter may be the internal kinematics

Different origins for the different types of ETGs?

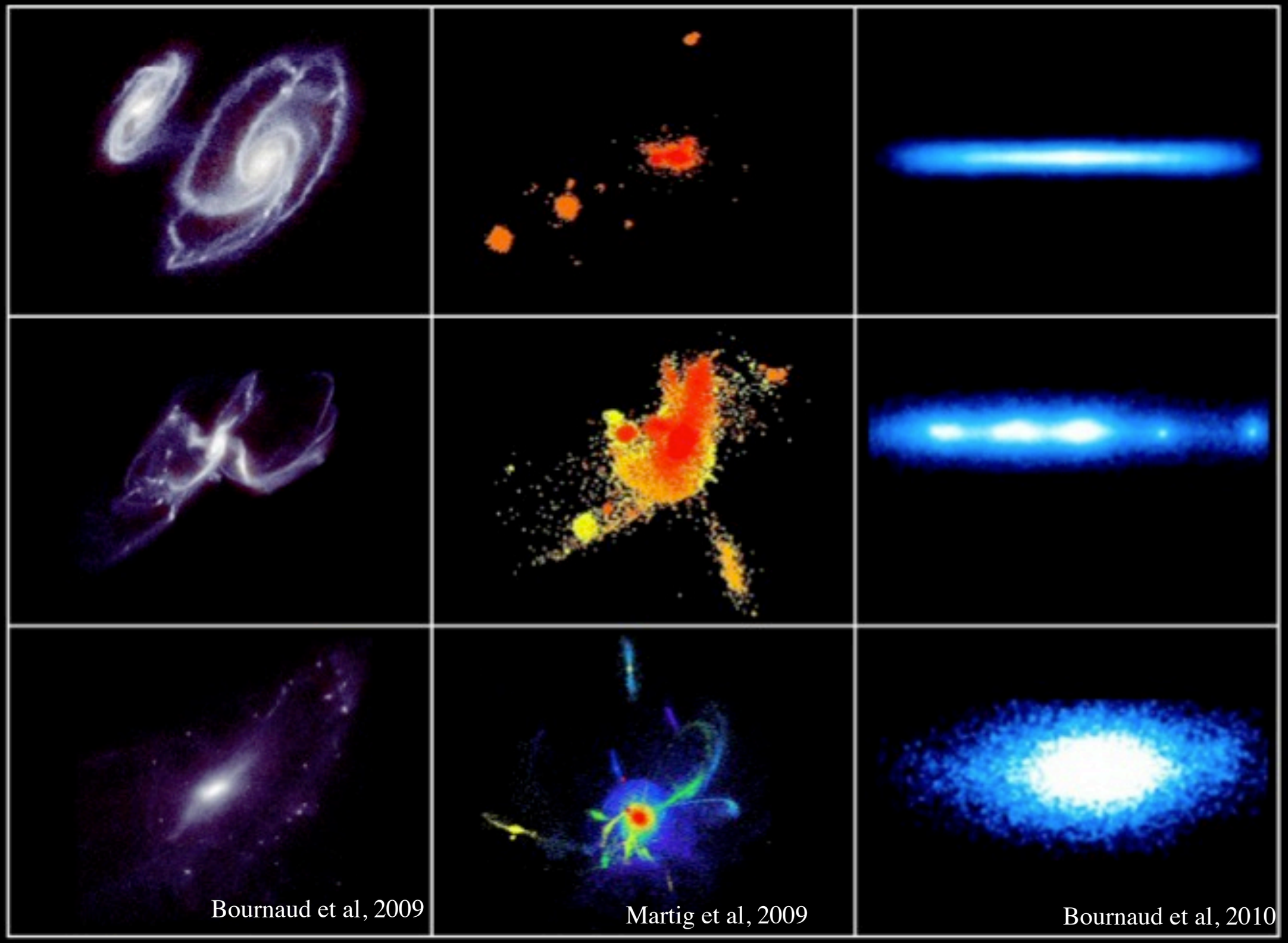



Capellari et al, 2010

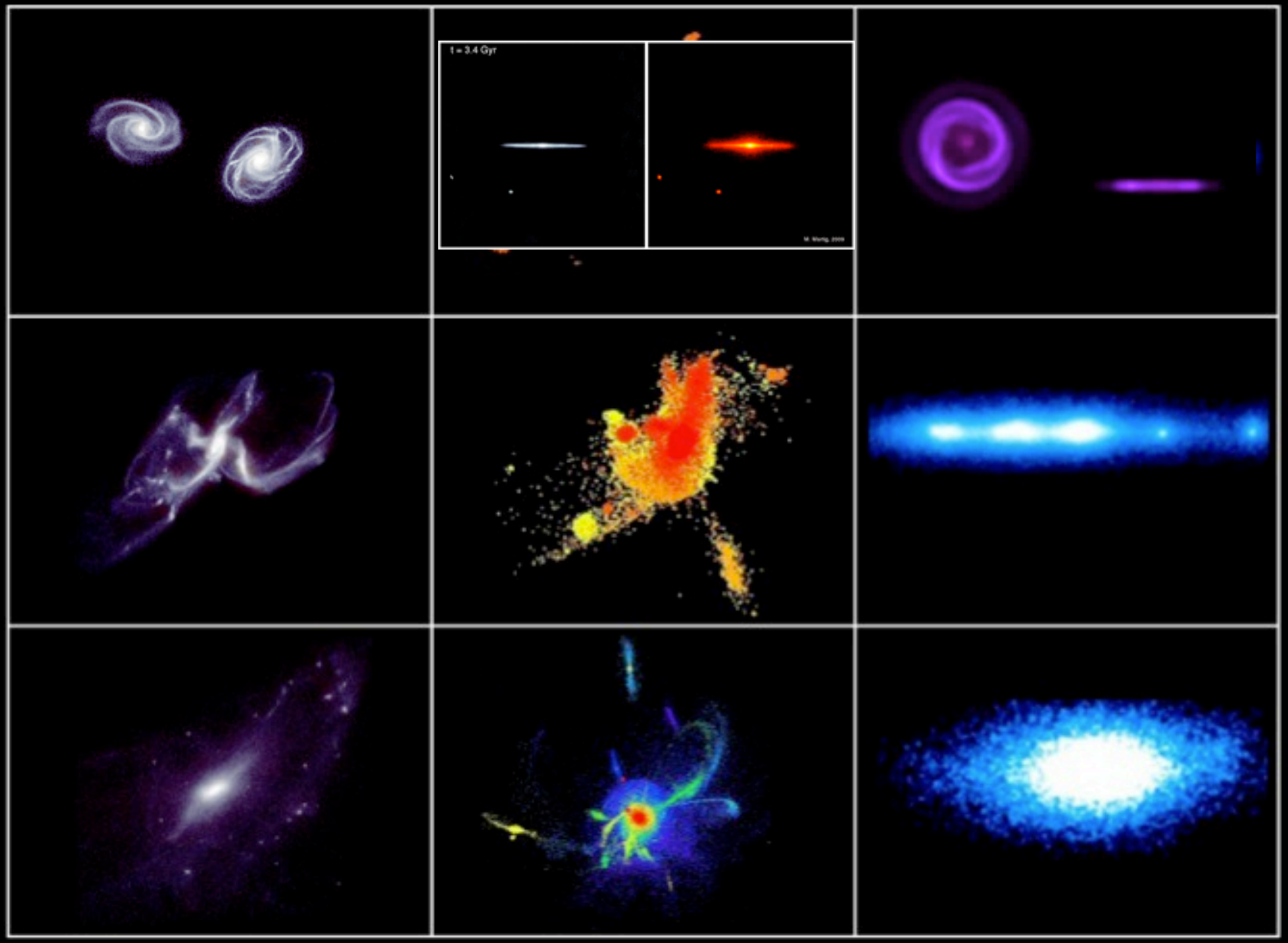
# Early-type galaxies...


# Various scenarios to form massive galaxies




Recent major merger | Merger history | Secular evolution

# Various scenarios to form massive galaxies

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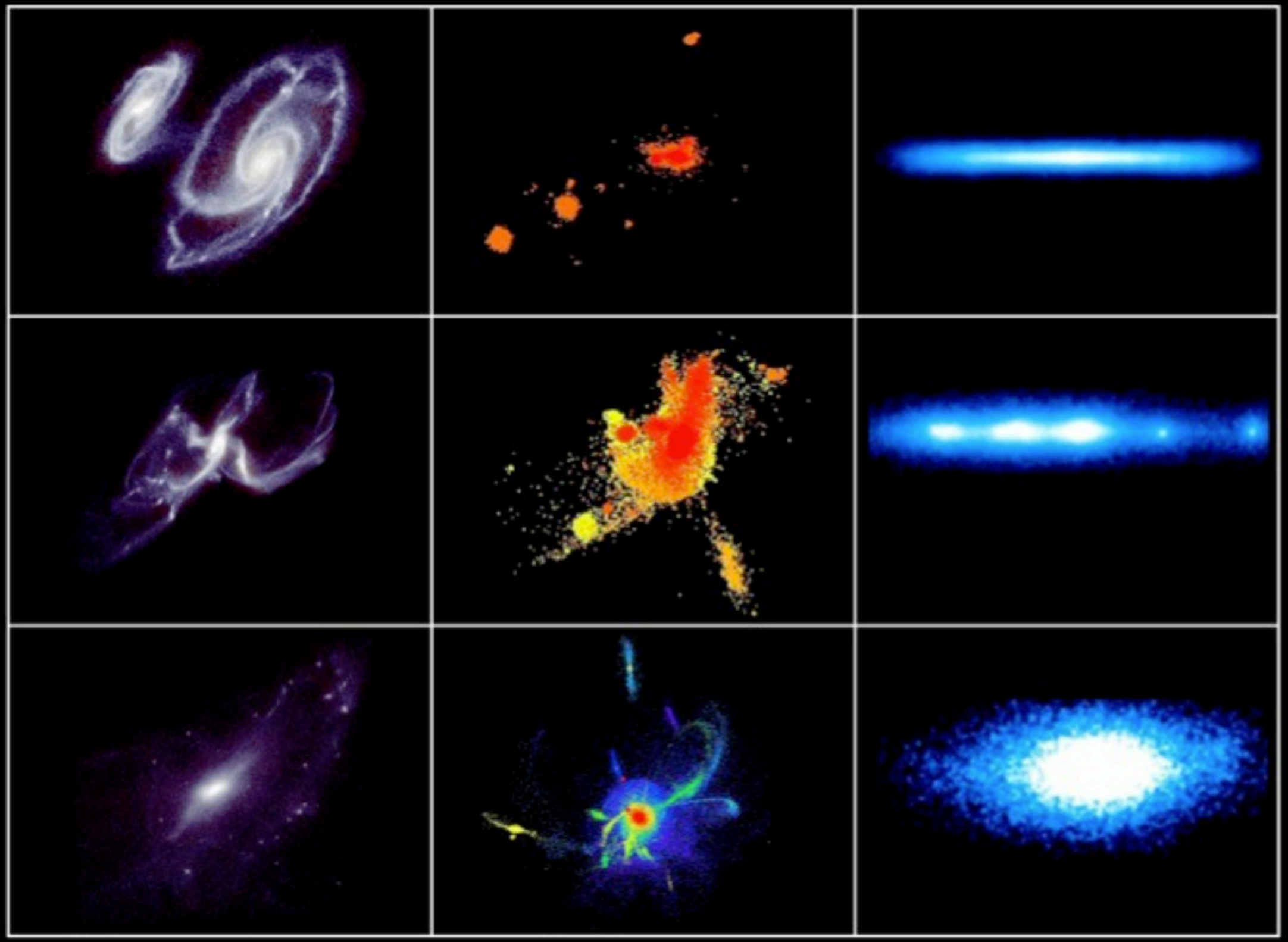
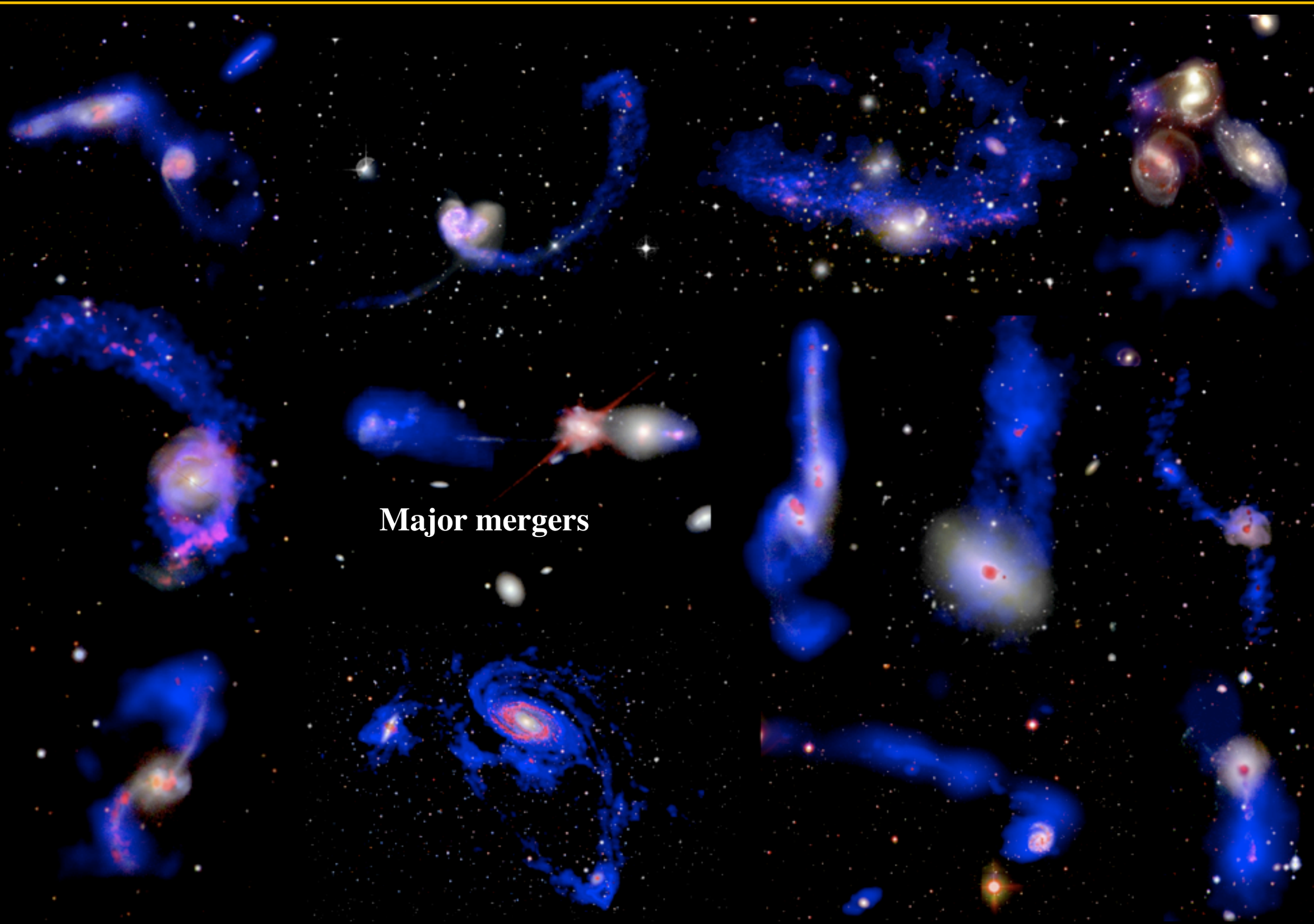
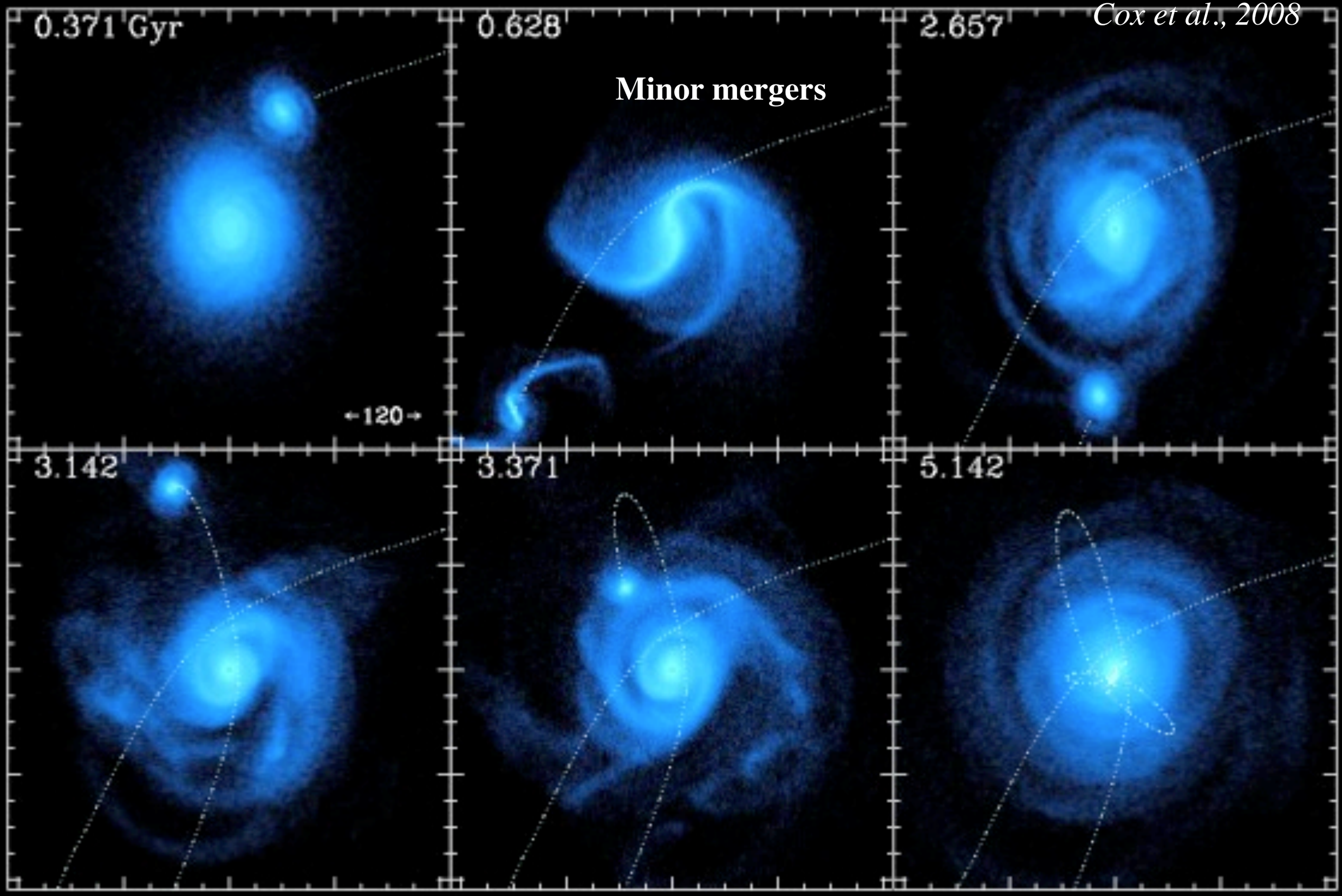


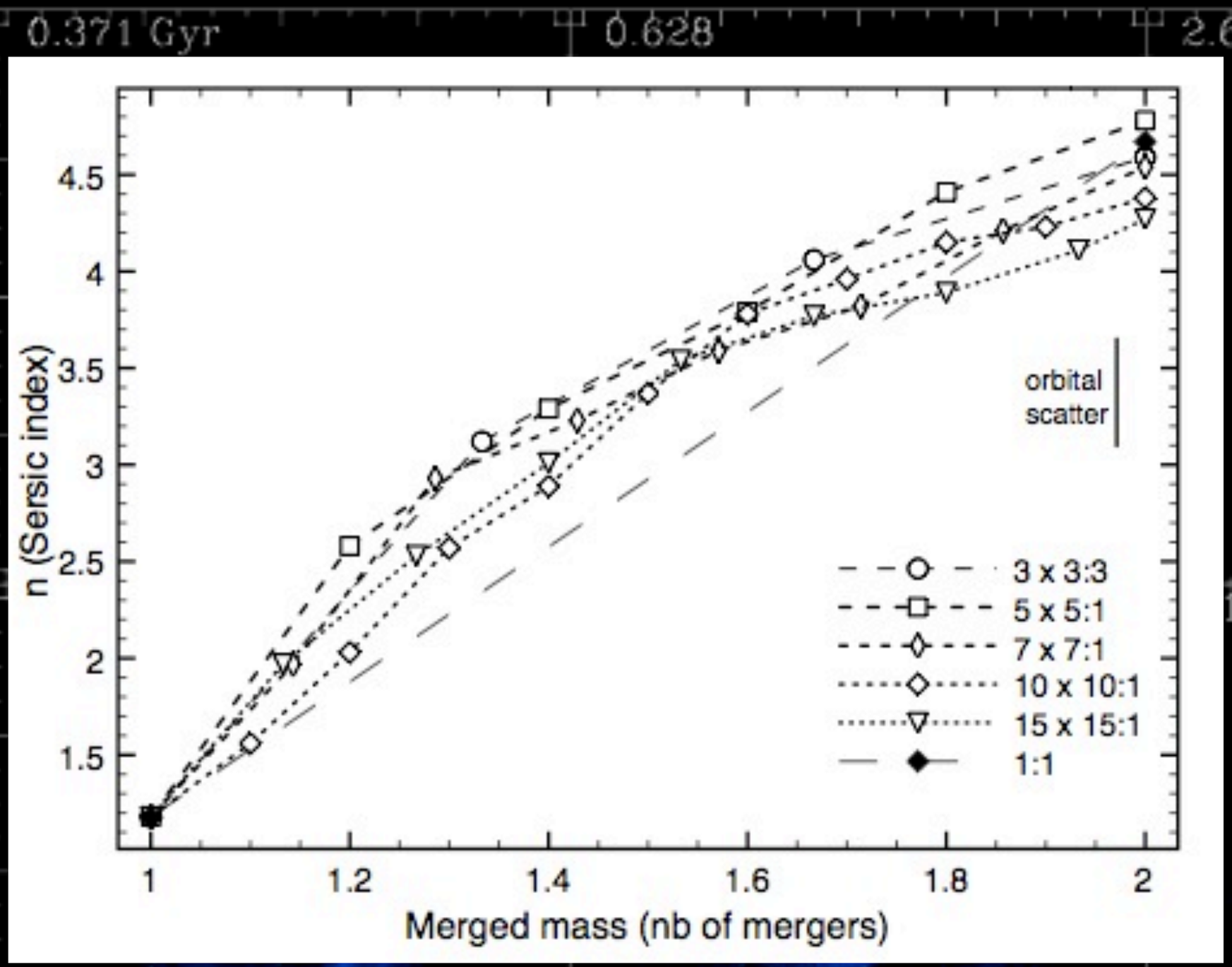
Growth of mass ? radius? sersic index?


Major mergers




*Cox et al., 2008*

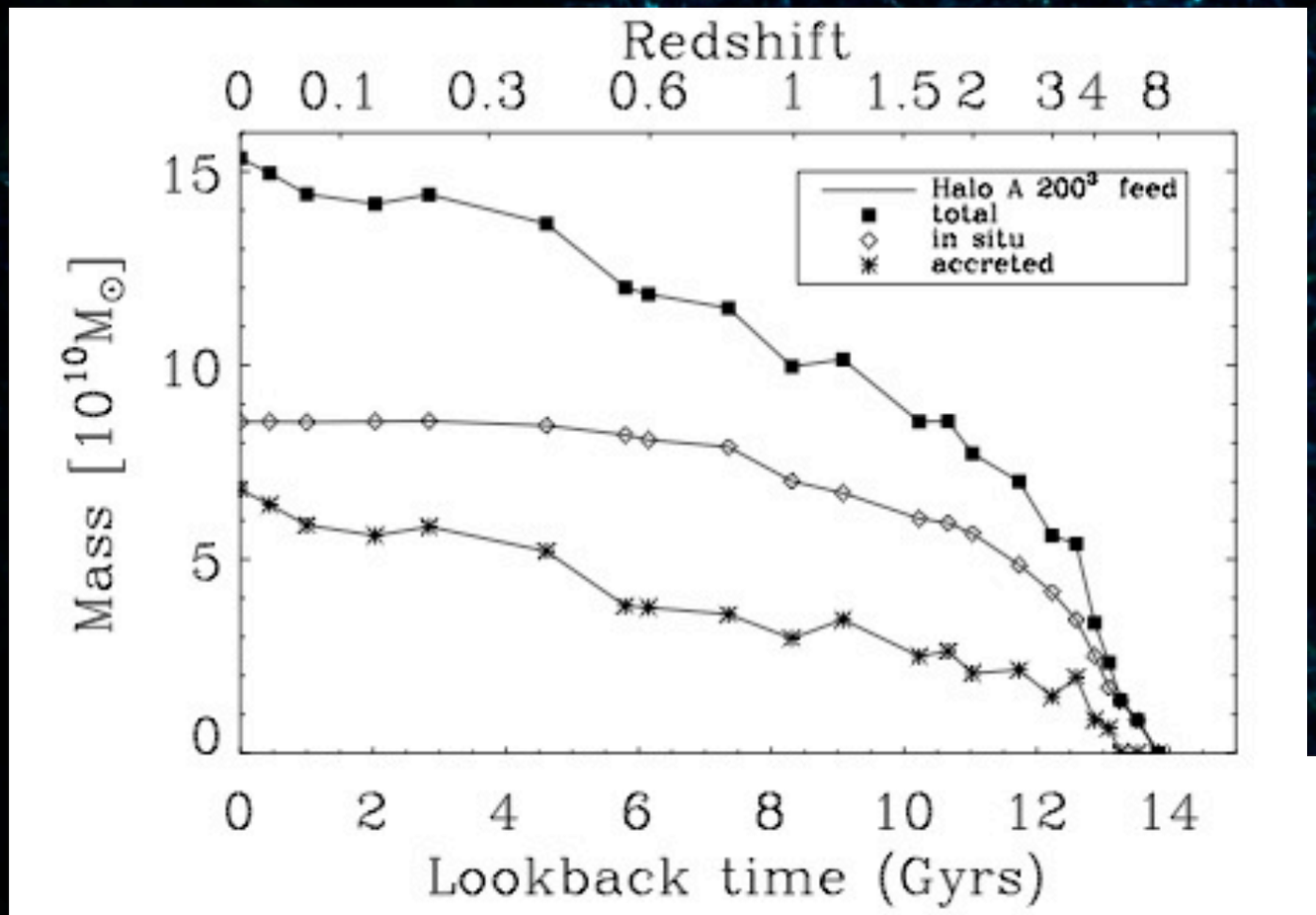
# Growth of mass ? radius? sersic index?




Multiple minor mergers have the same ability as major mergers to increase the Sersic index

*Bournaud, Jog & Combes, 2007*

# Growth of mass ? radius? sersic index?

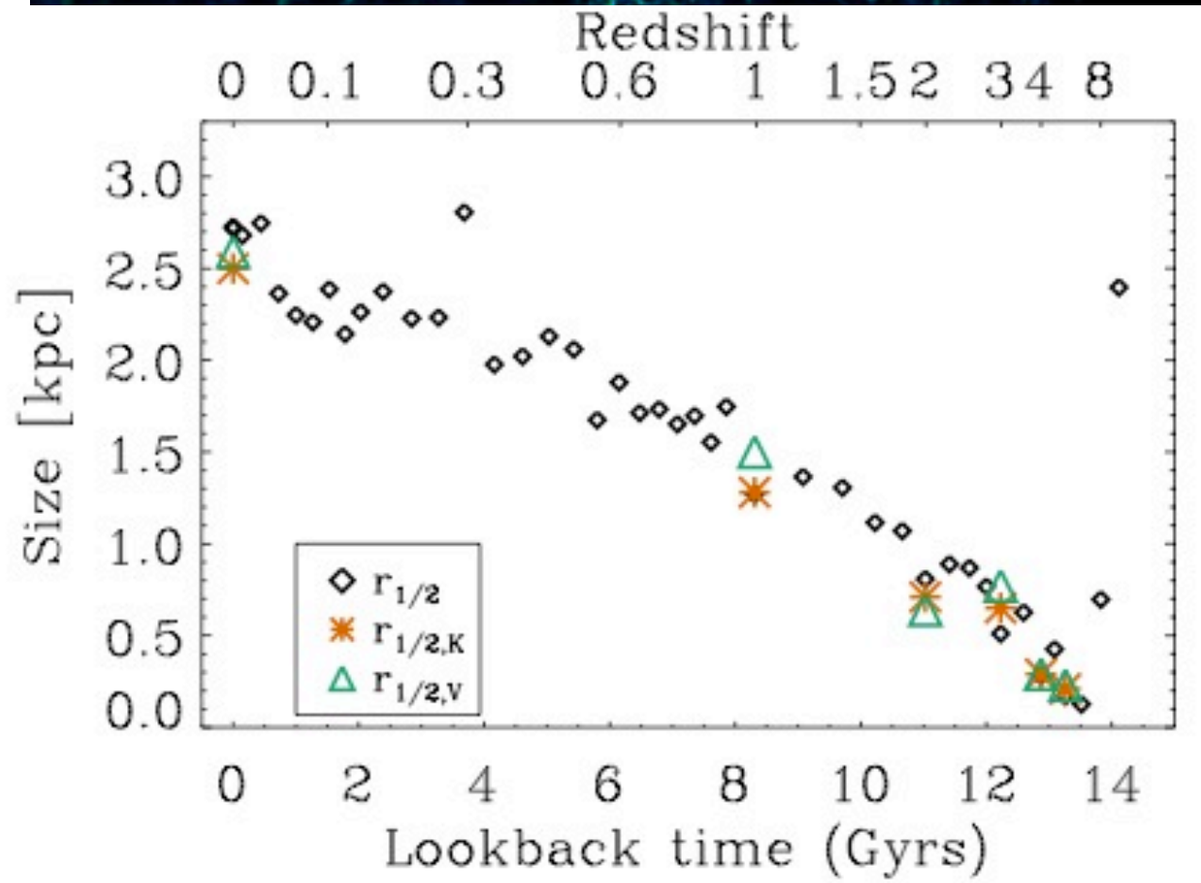



*Cosmological simulations*

- At high z, primary role of in situ star formation fueled by gas accretion and cooling
- Below z<1, mass growth primary due to mass accretion

*Naab et al., 2009*

Growth of effective radius to minor mergers



# Minor/major dry/wet mergers versus mass

- $M_* > 2\ 10^{11}\ M_\odot$ stellar mass growth by recent major dry mergers

*Hopkins et al., 2008; Bernardi et al., 2010*

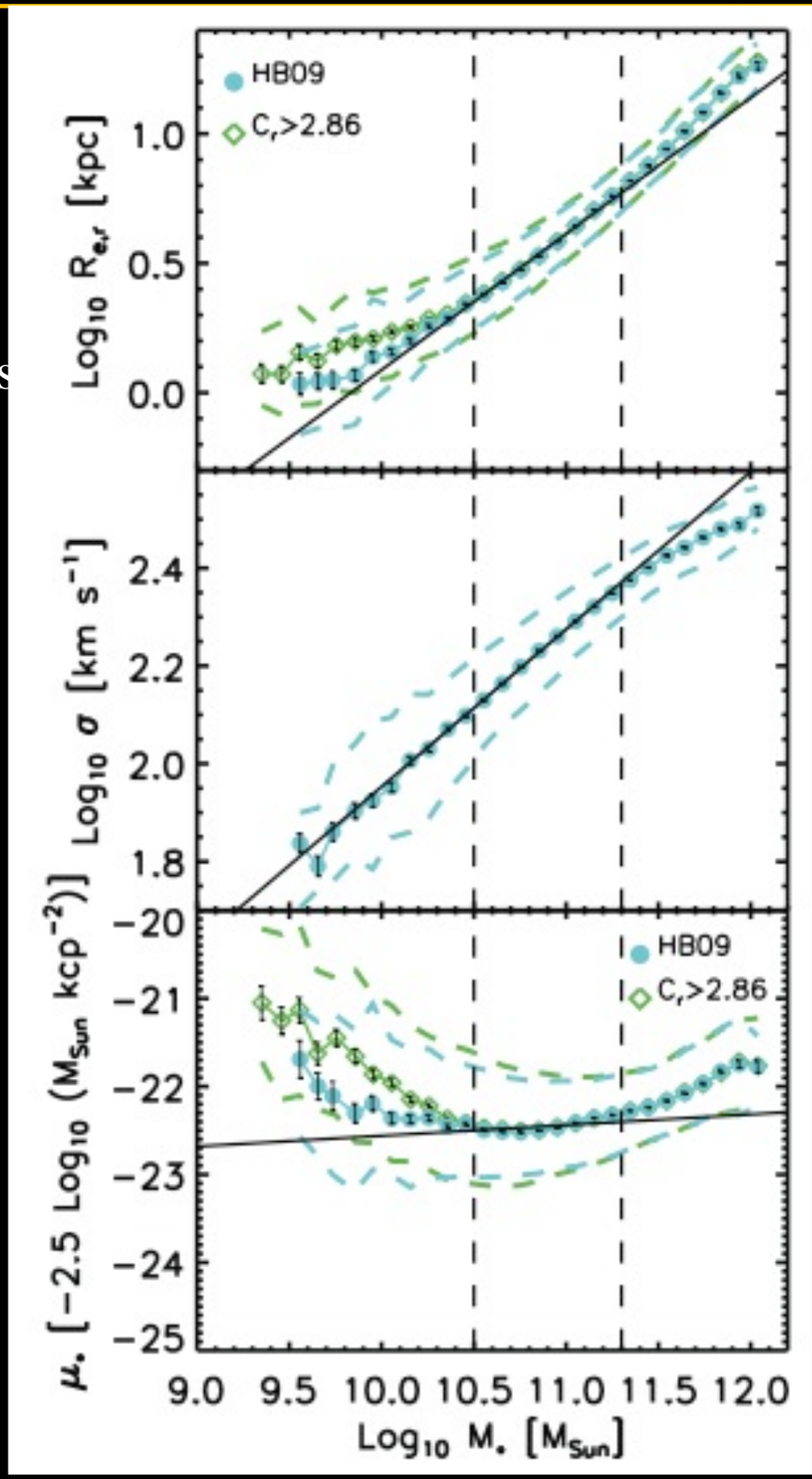
- $M_* > 10^{10}\ M_\odot$: only 20% of ETGs made since z=1 due to major merger

*Lopez-Sanjuan et al., 2010*

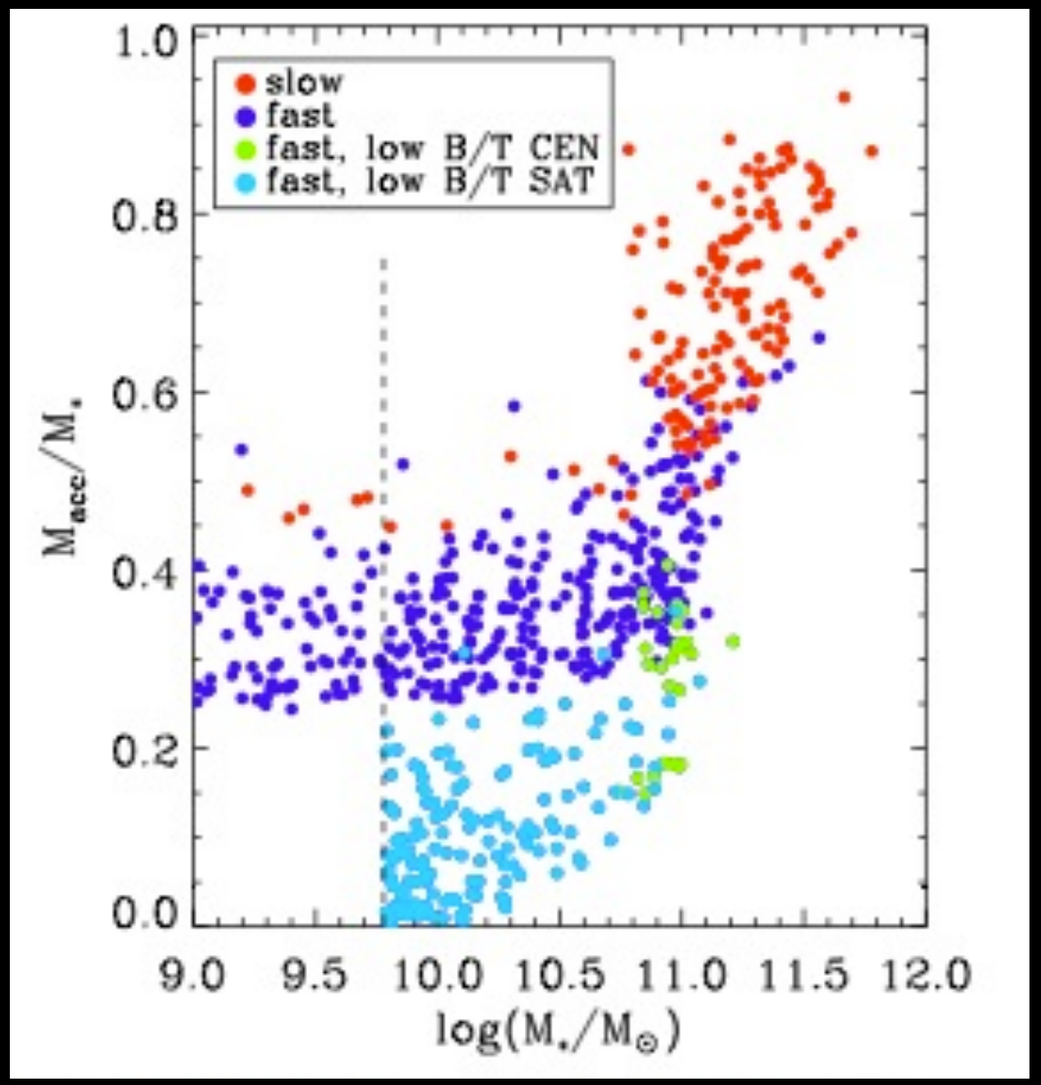
- Minor (dry) mergers play a role for the least massive and most massive spheroids

*Hopkins et al., 2010*

....

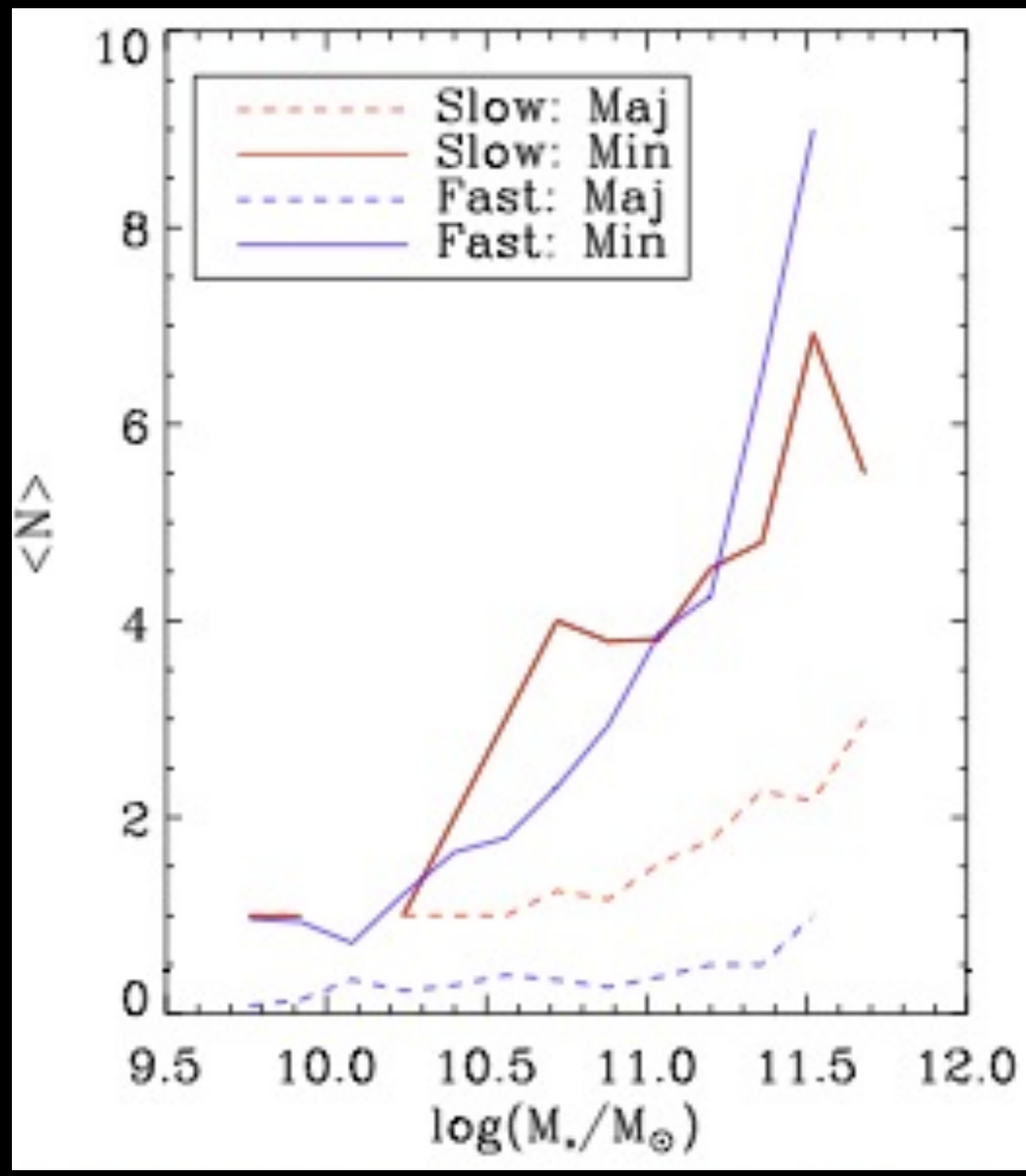


# Minor/major dry/wet mergers versus slow/fast rotators



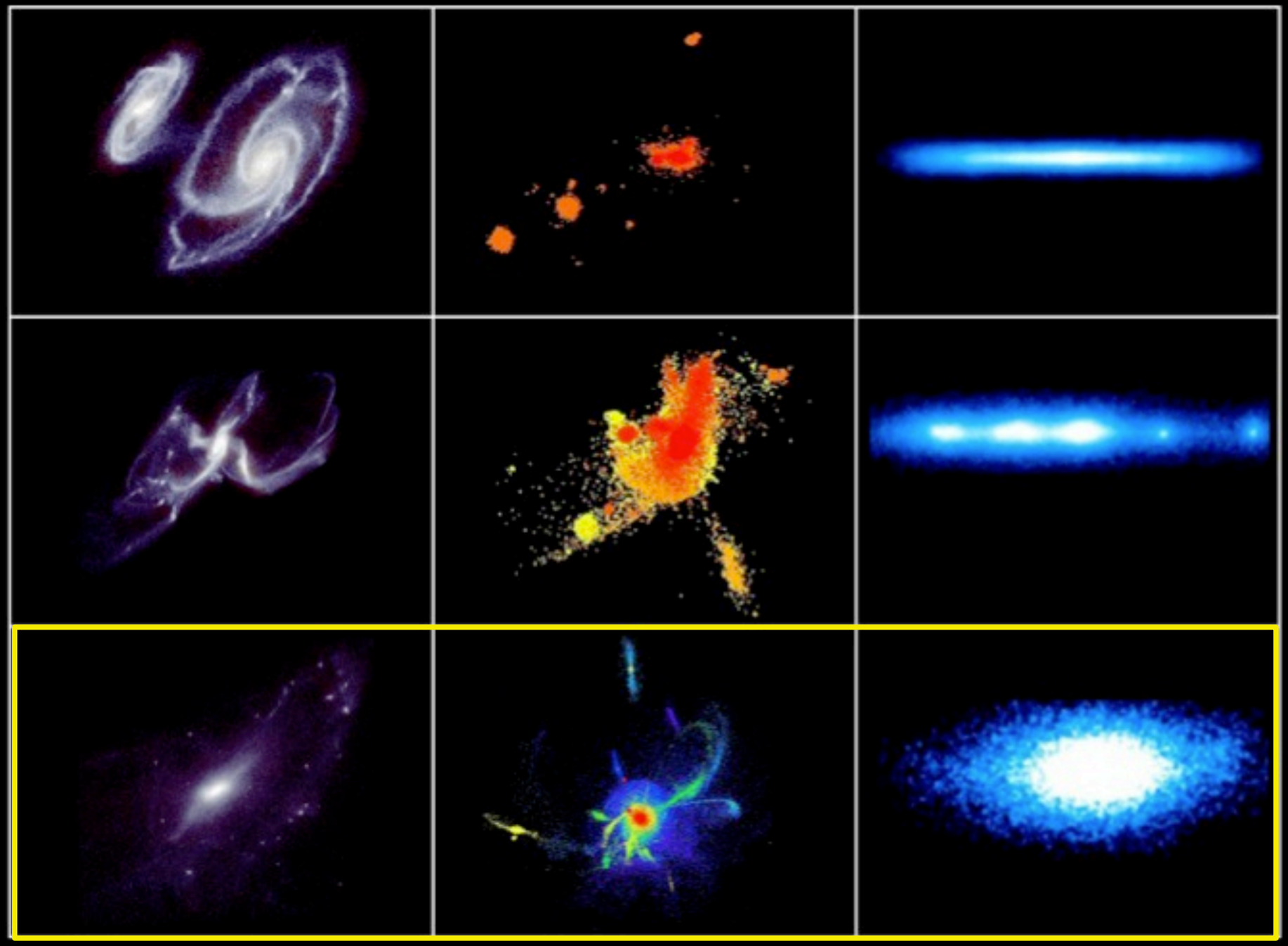

- Fast rotators have accreted less than 50%, and known no major merger

*Khochfar et al., 2011*




Slow rotators: 50-90% stellar mass accreted from satellites, with progenitors having known 3 major mergers
- Last gas-rich major merger at z>1.5
- Minor mergers destroy disk, decrease specific angular momentum

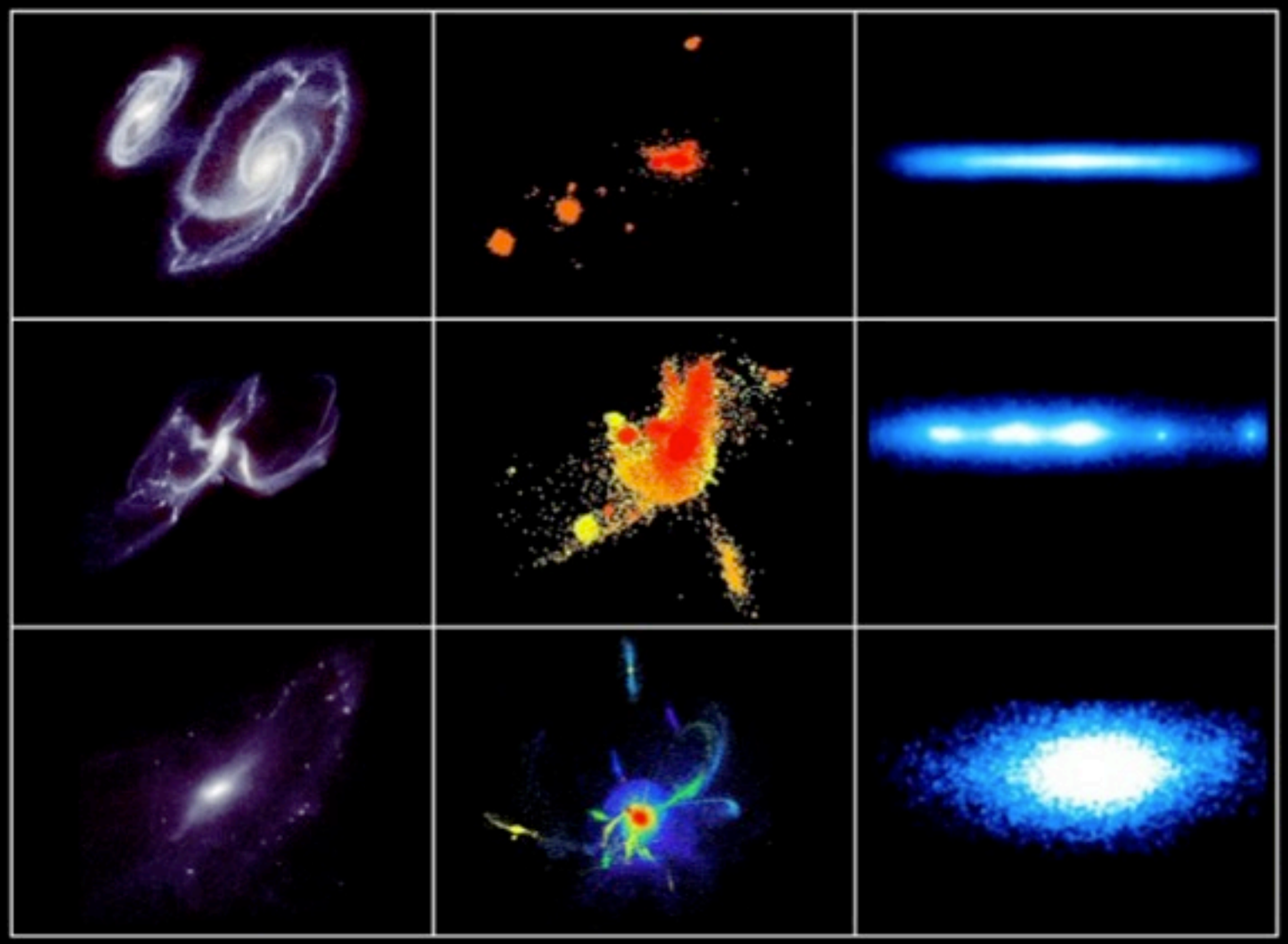
# Various scenarios to form massive galaxies



Recent major merger | Merger history | Secular evolution

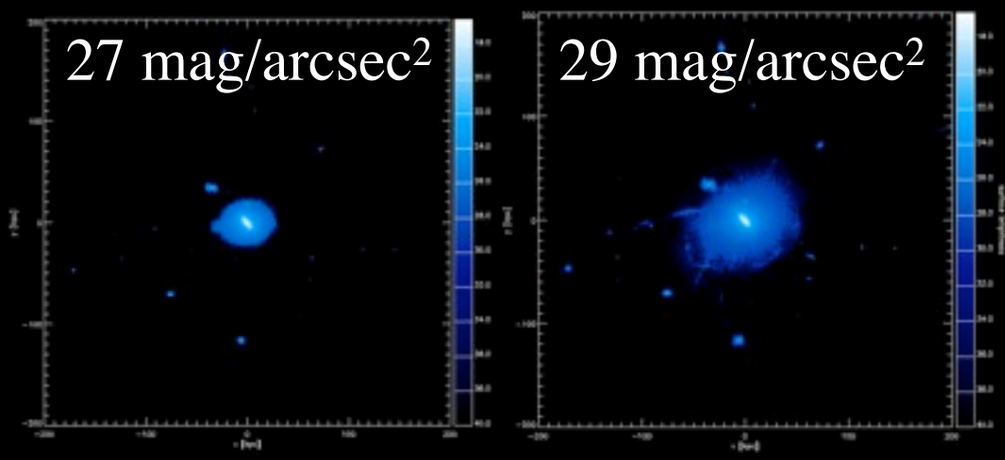
... that produce various types of fine structures: tails, plumes, streams, shells, etc...

# Various scenarios to form massive galaxies



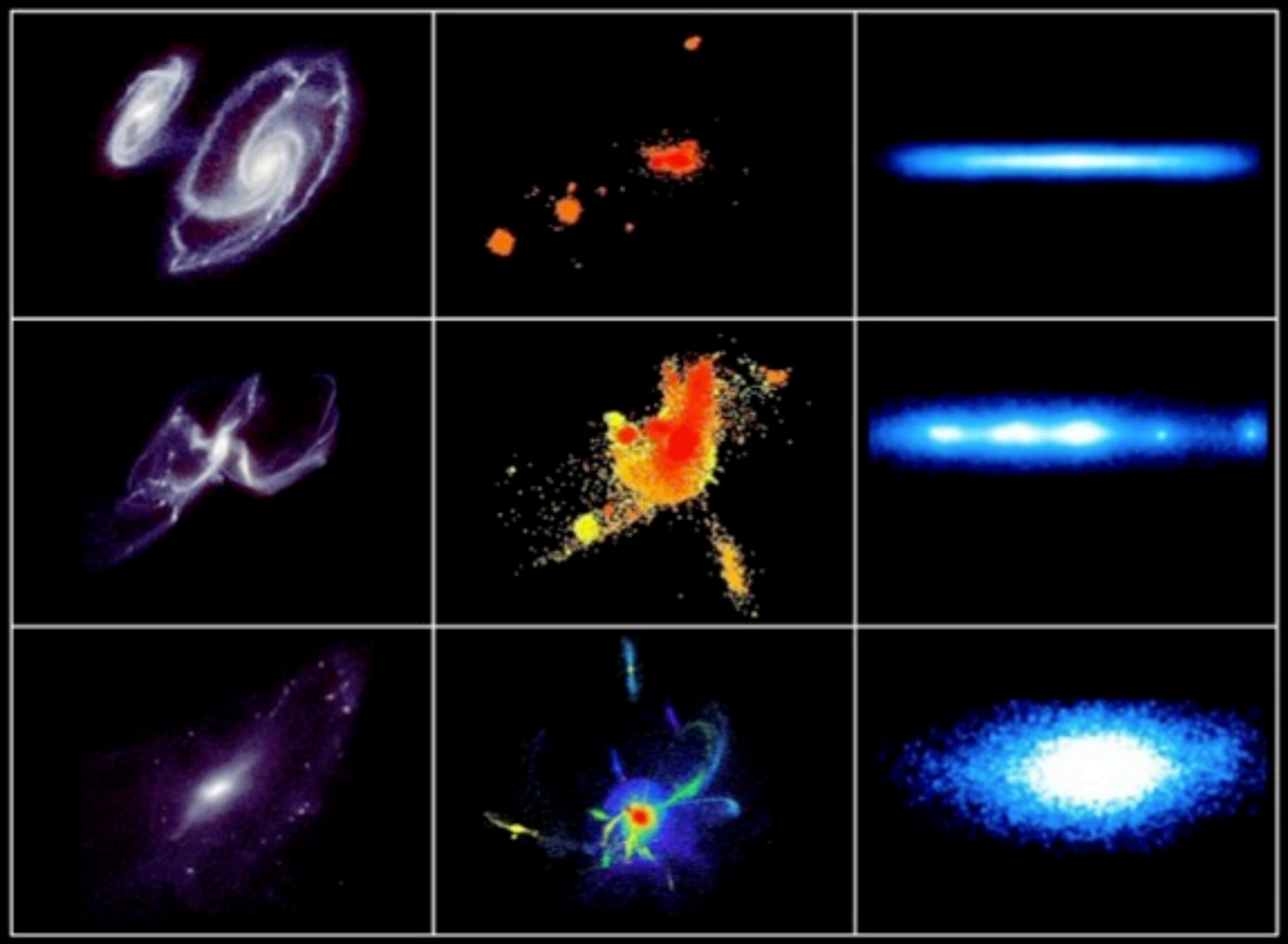
Tracing the origin of ETGs with fine structures

- Issues:
- how to detect the fine structures?




*Using specific observing methods, and dedicated pipeline (Elixir-LSB), MegaCam can now do it!*

# Various scenarios to form massive galaxies



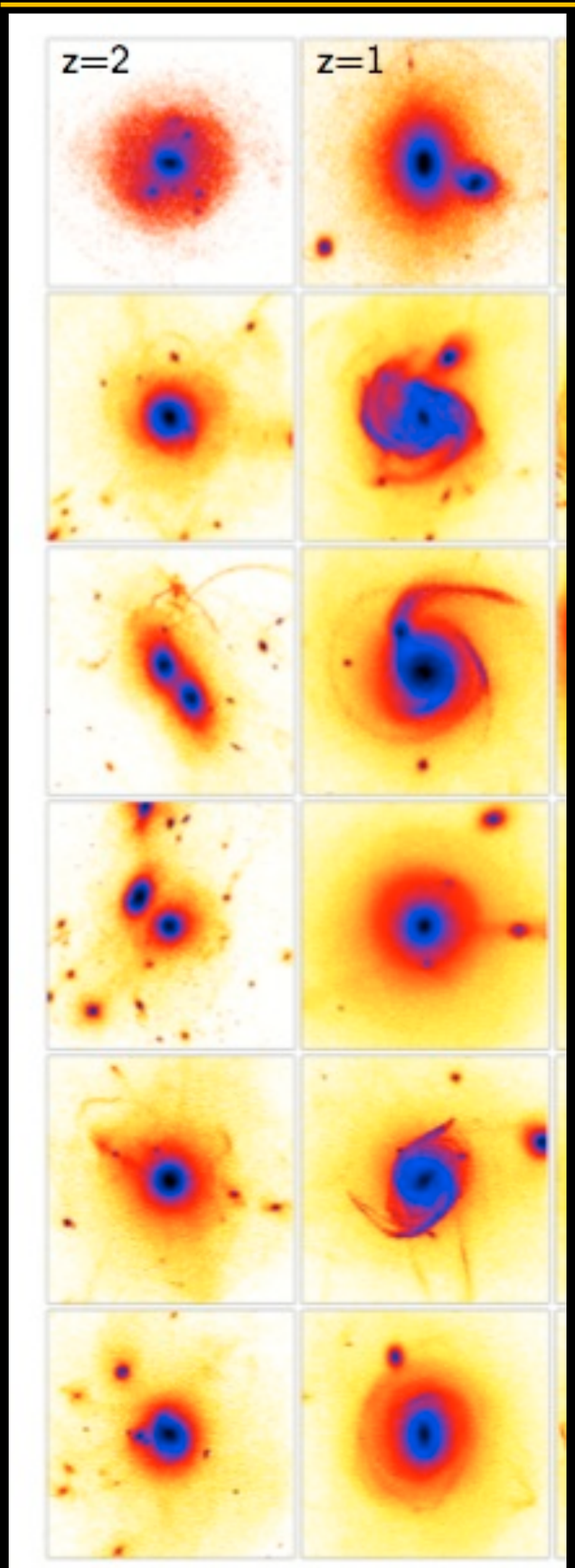
Tracing the origin of ETGs with fine structures

• Issues:
- how to detect the fine structures?

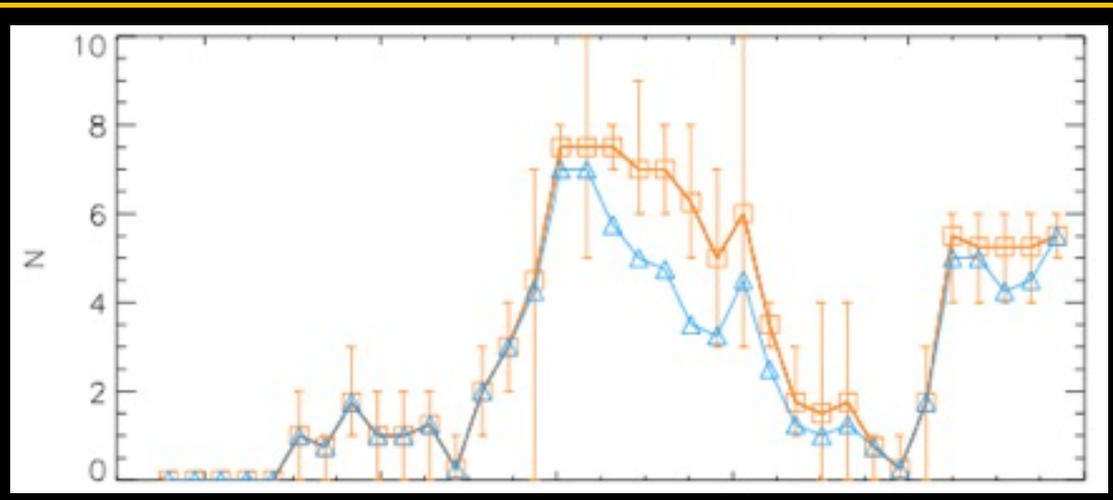
- the memory of past accretion might be lost:
  ✓ with time

*addressed by numerical simulations*

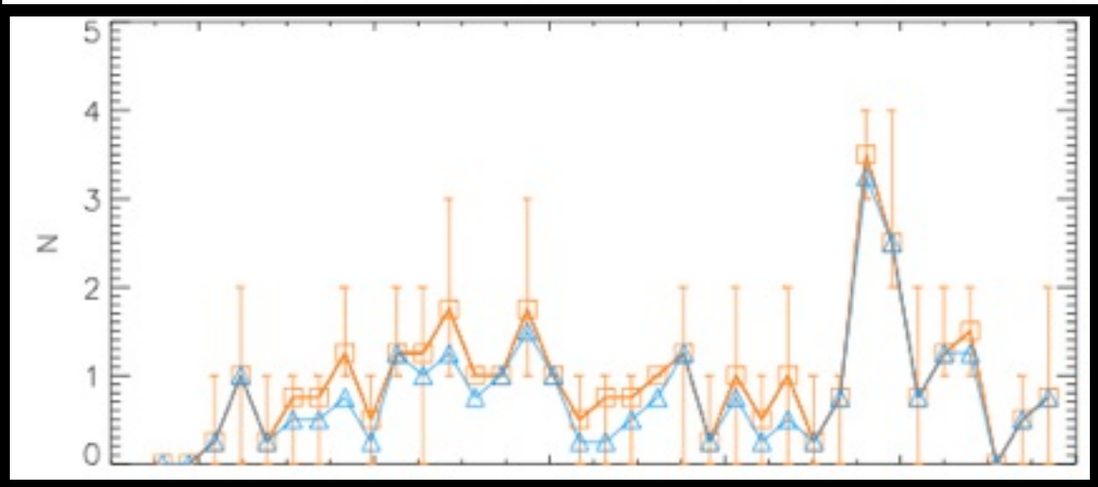
# Survival of fine structures (simulations)



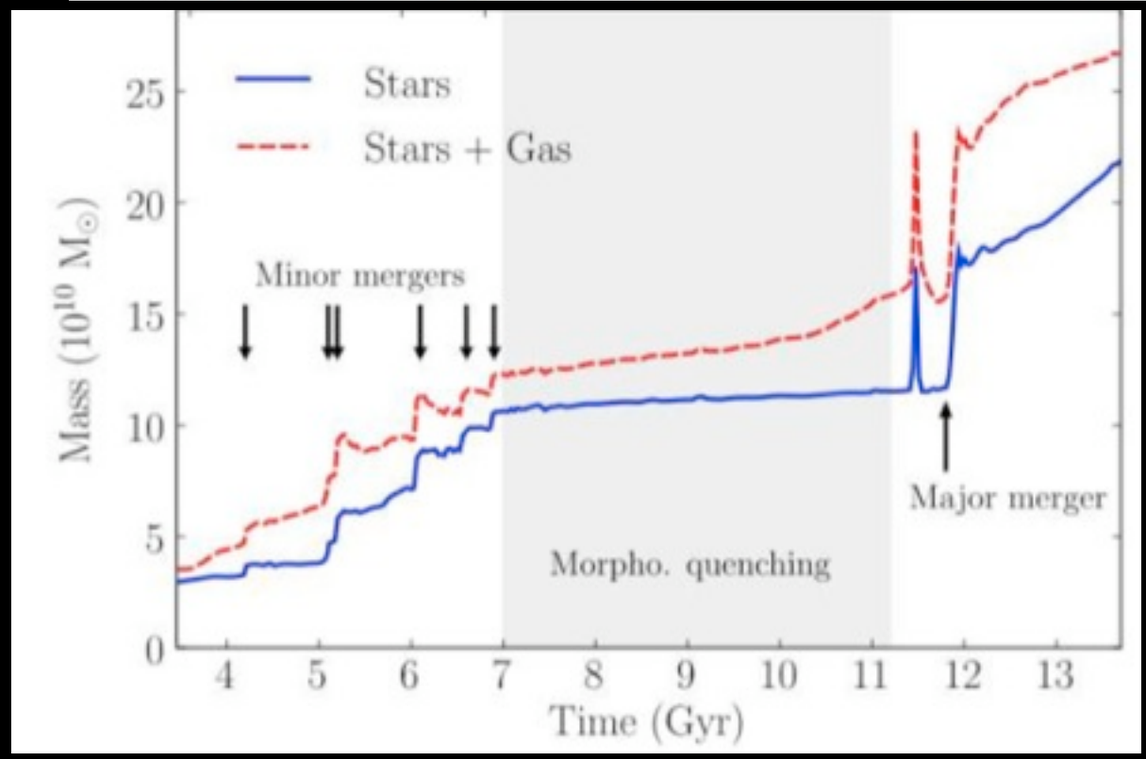

- Number of shells




- Number of tidal tails



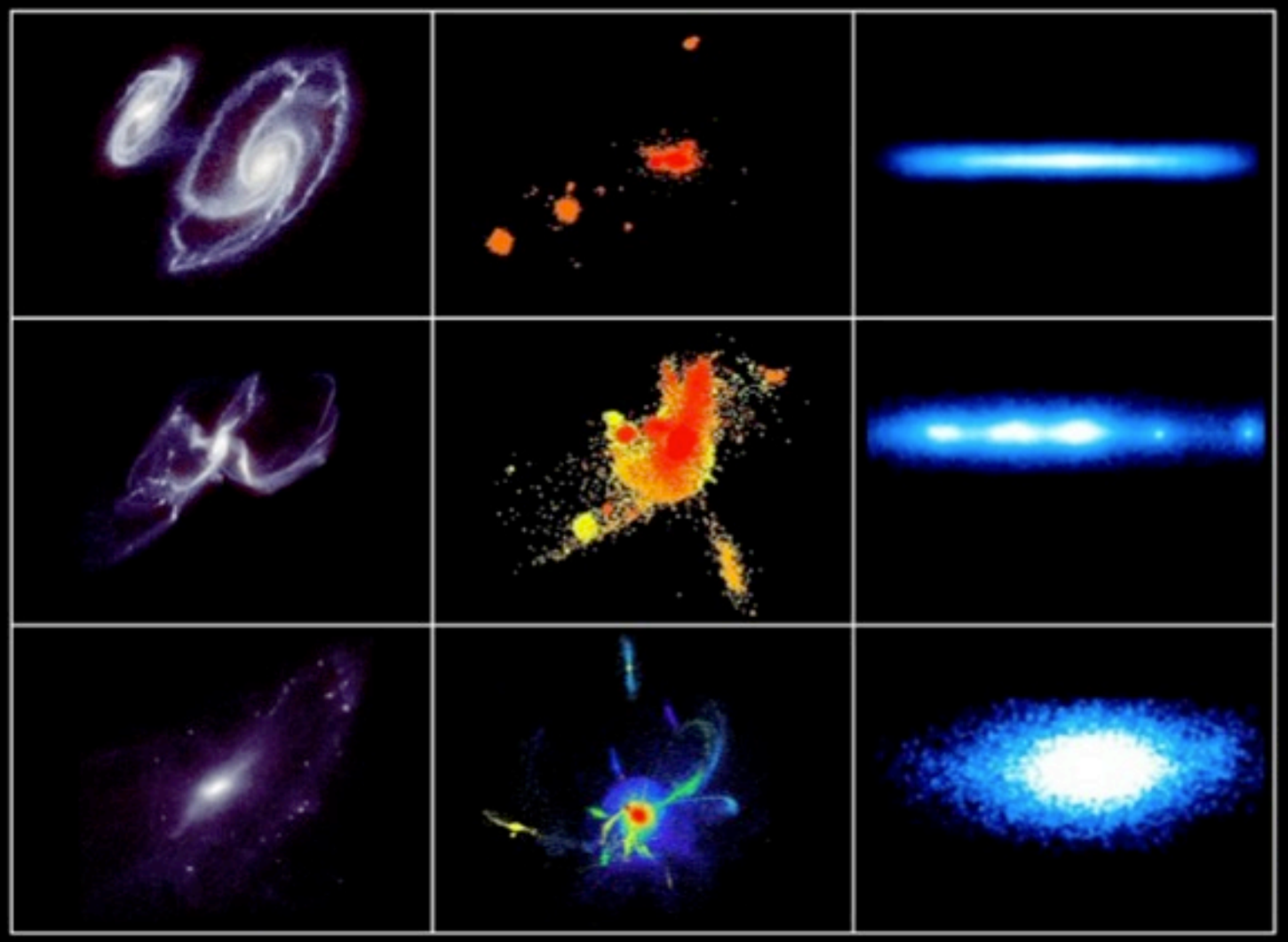

- Mass assembly




Michel-Dansac et al, 2011

Martig et al, 2009

# Various scenarios to form massive galaxies



Tracing the origin of ETGs with fine structures

• Issues:
- how to detect the fine structures?

- the memory of past accretion might be lost:

✓with the environment (e.g. in clusters)

*two MegaCam surveys of nearby ETGs*
✓*field, groups: Atlas-3D - 50 objects*
✓*cluster: NGVS - 60 objects*

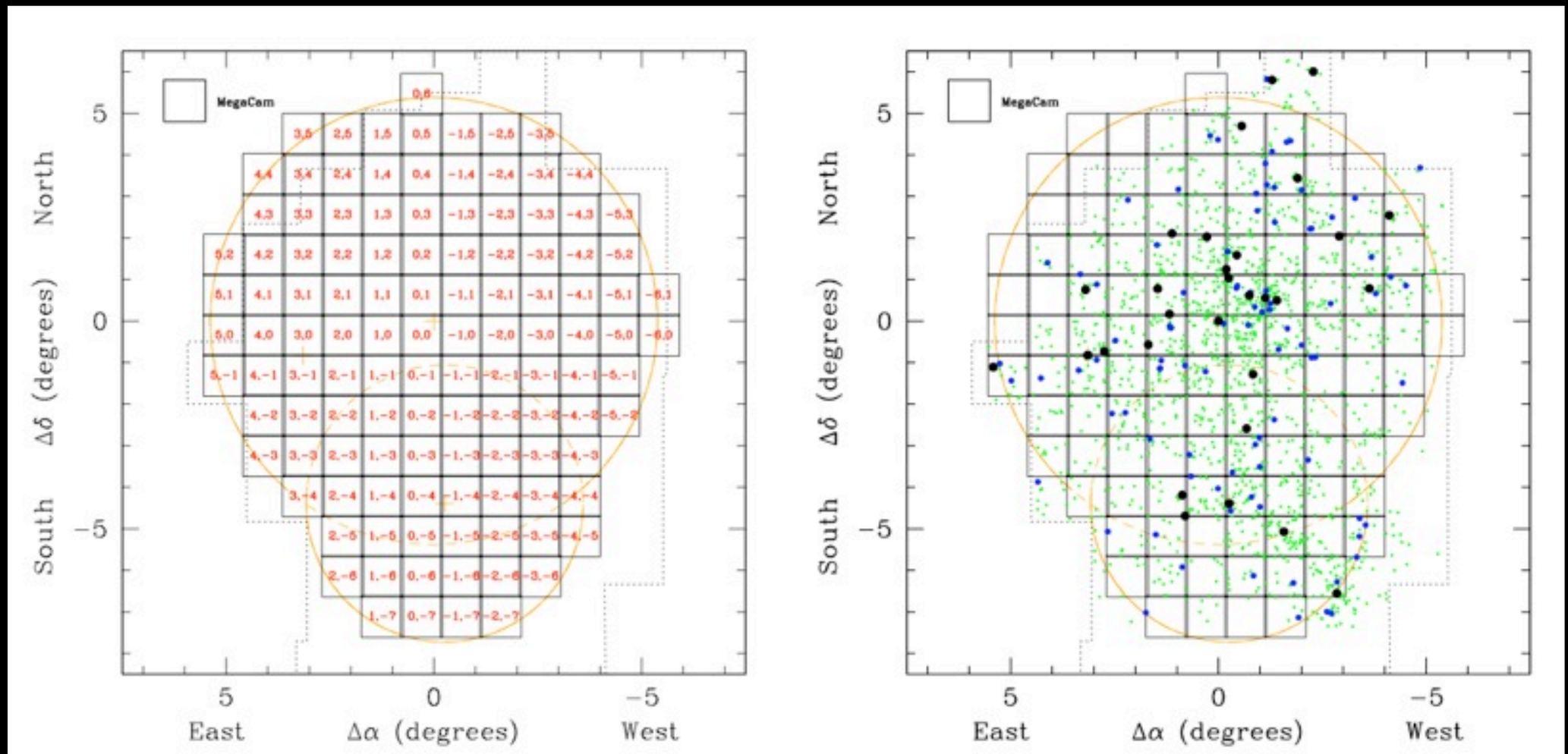
# The Next Generation Virgo Cluster Survey

A Large Programme with CFHT / MegaCam
(771 hours over semesters 2009A-2012A

- 104 square degrees in 5 bands (u,g,r,i,z)

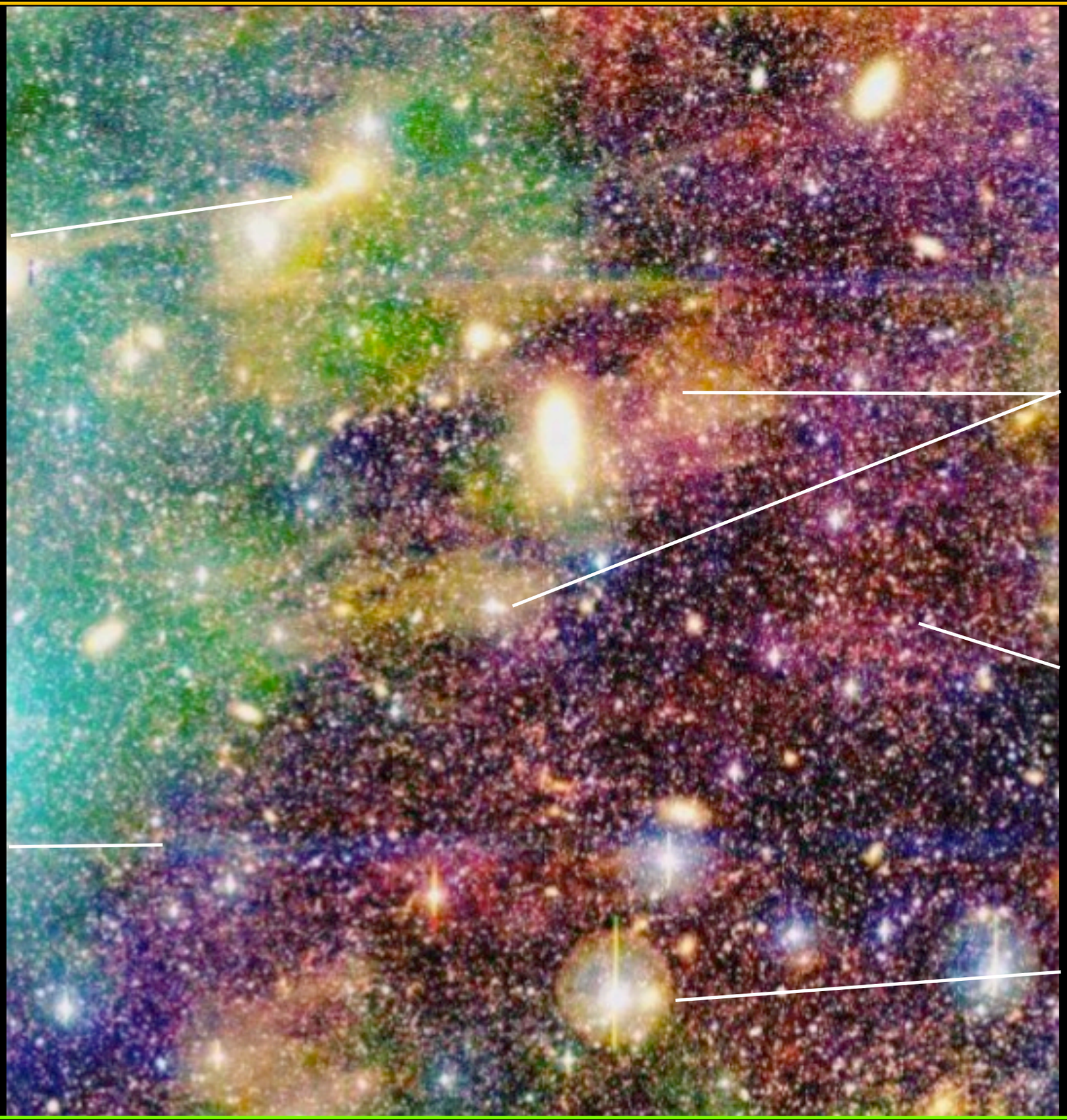
- seeing(i)<0.6”
- *g*~25.7 AB mag
- SB (g)< 29 mag arcsec$^{-2}$

u=6400 s
g=3200 s
r=4800 s
i=2050 s
z=4400 s




Ferrarese et al, 2011

# Trouver ses petits... in NGVS images



Stellar streams

Galactic cirrus

Faint foreground stars

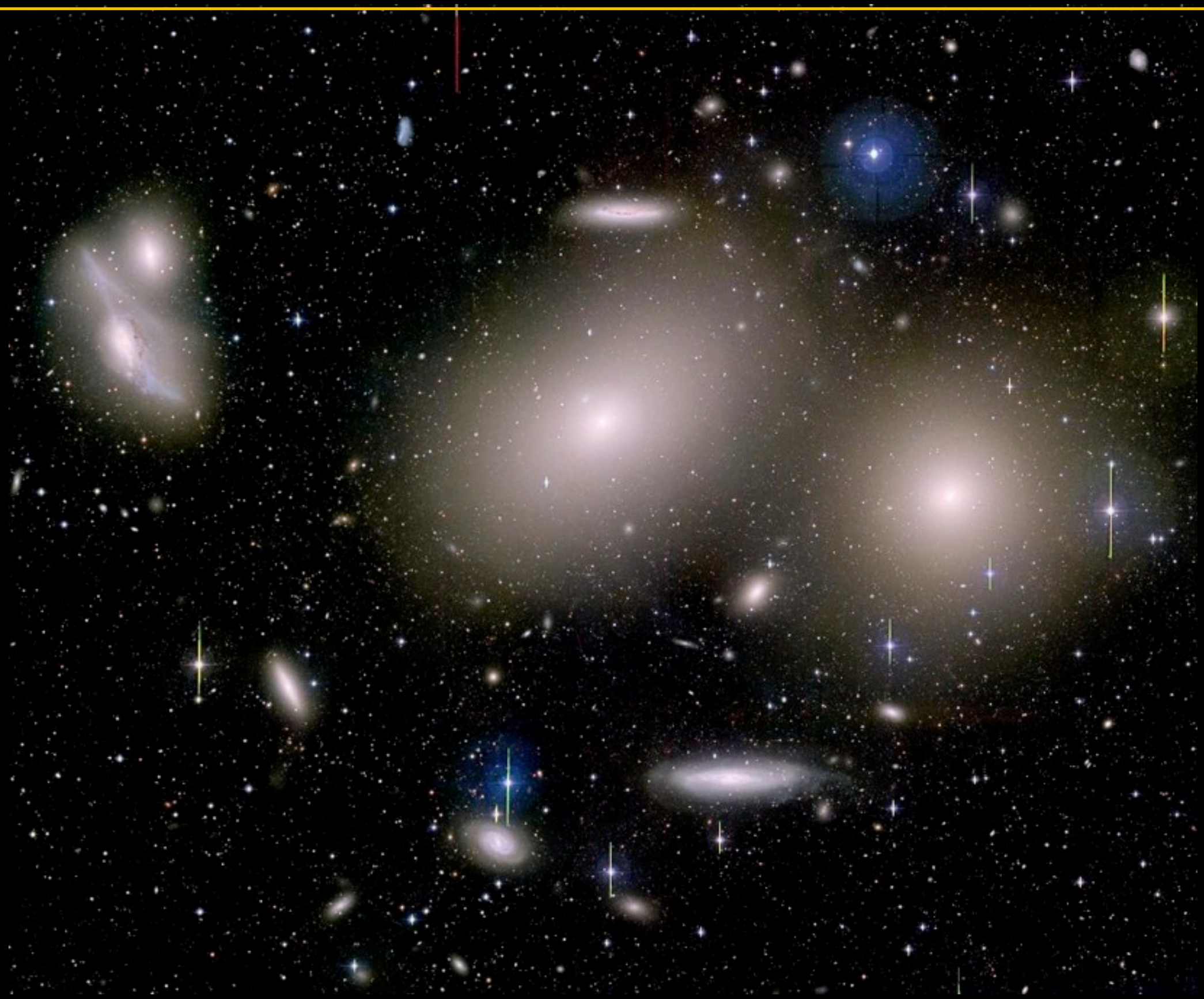
Instrumental artifacts

Halos of bright stars

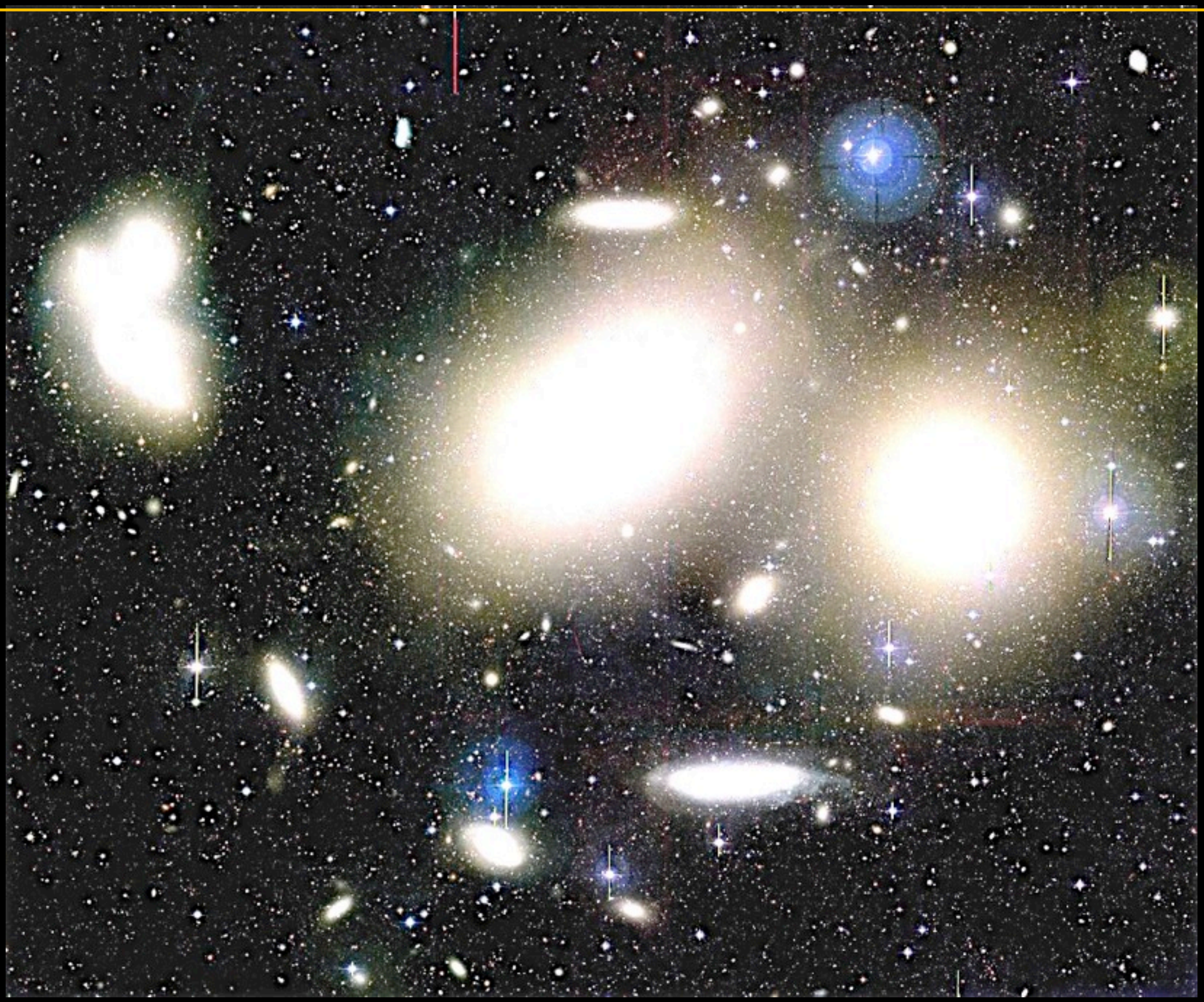
Plus galaxies

# Ultra faint dwarfs in the NGVS

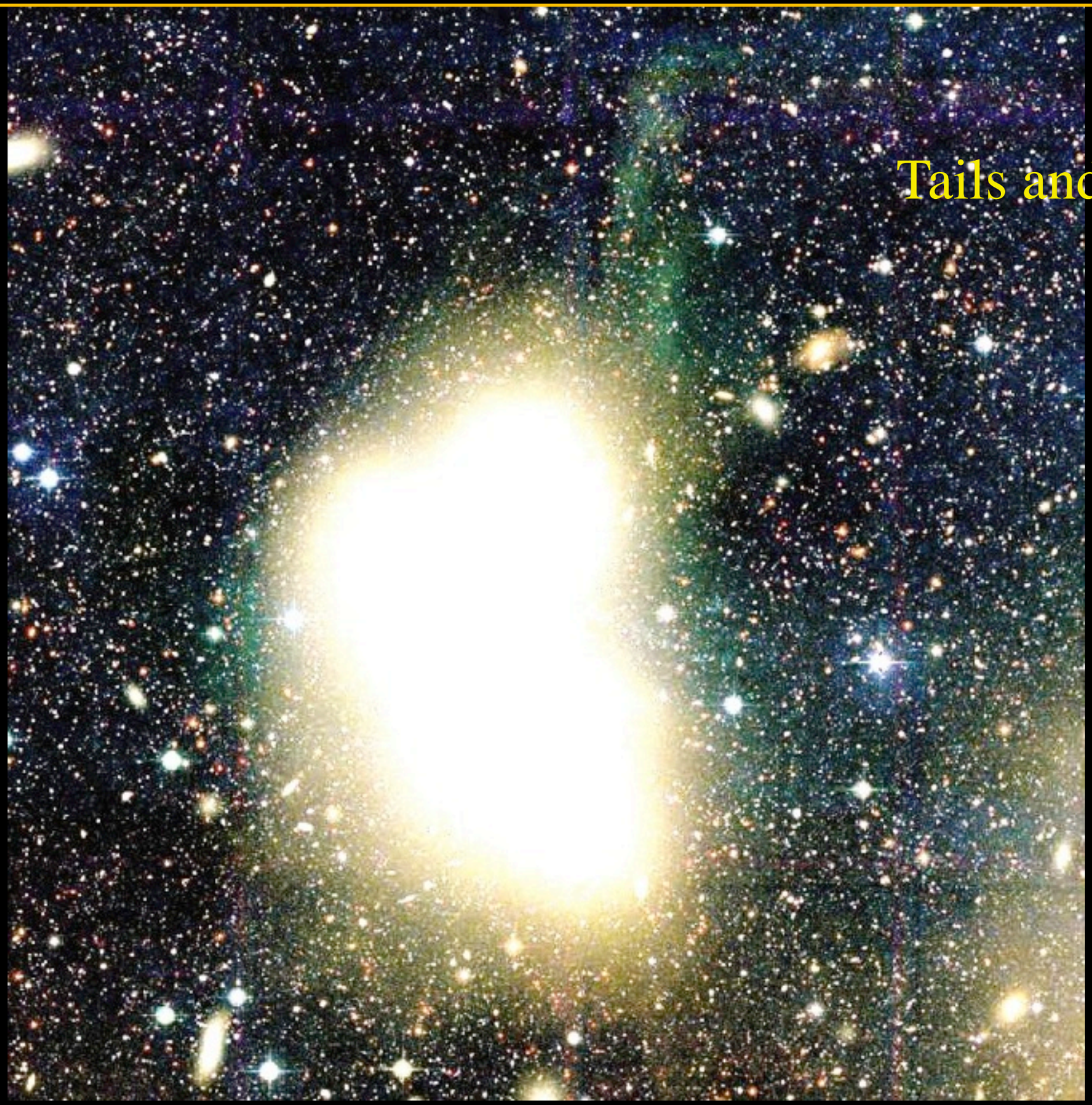
# Center of Virgo: the NGVS view



# Center of Virgo: the NGVS view




Tails and streams



Tails and streams

# NGC 4649 (M 60) - NGVS

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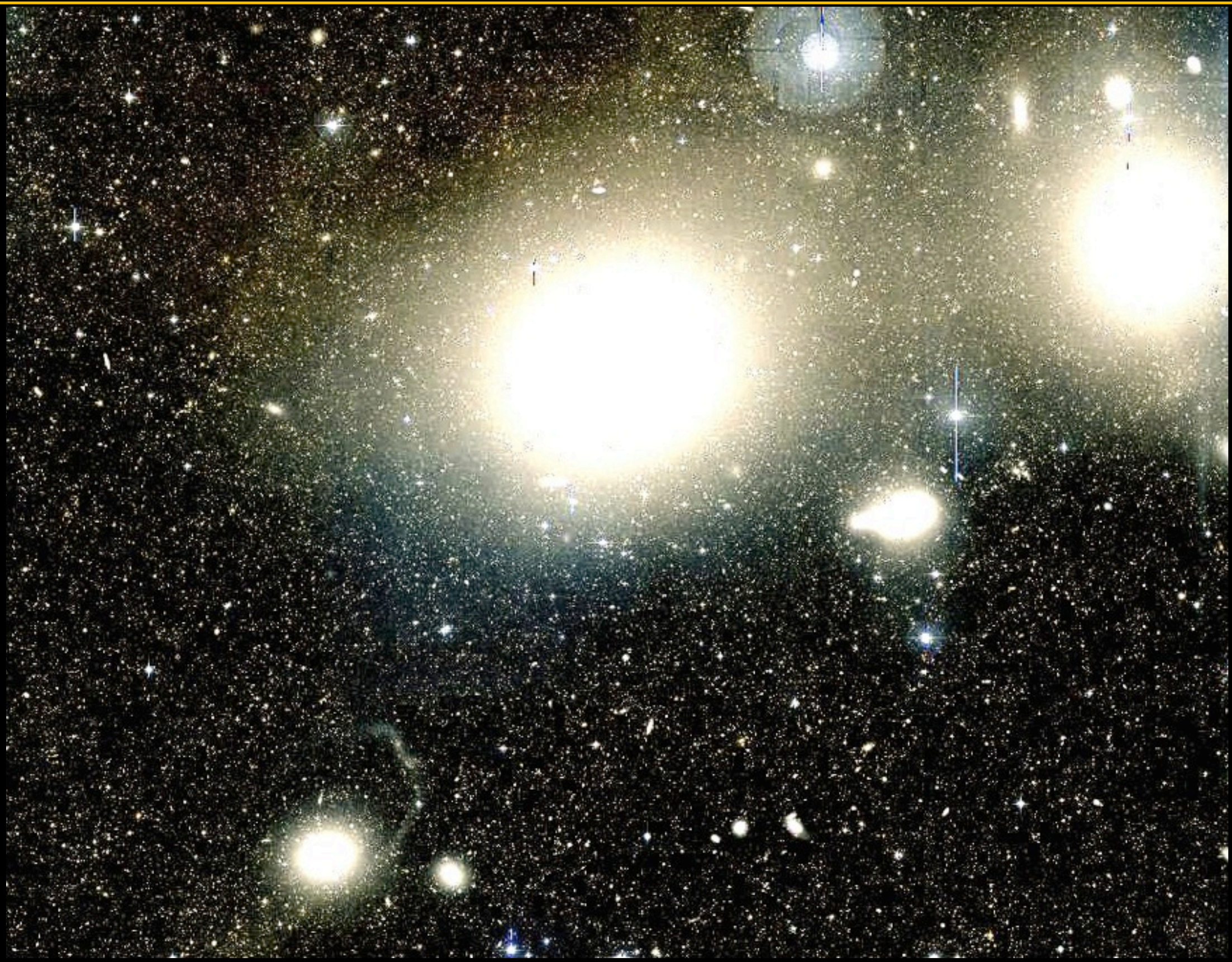
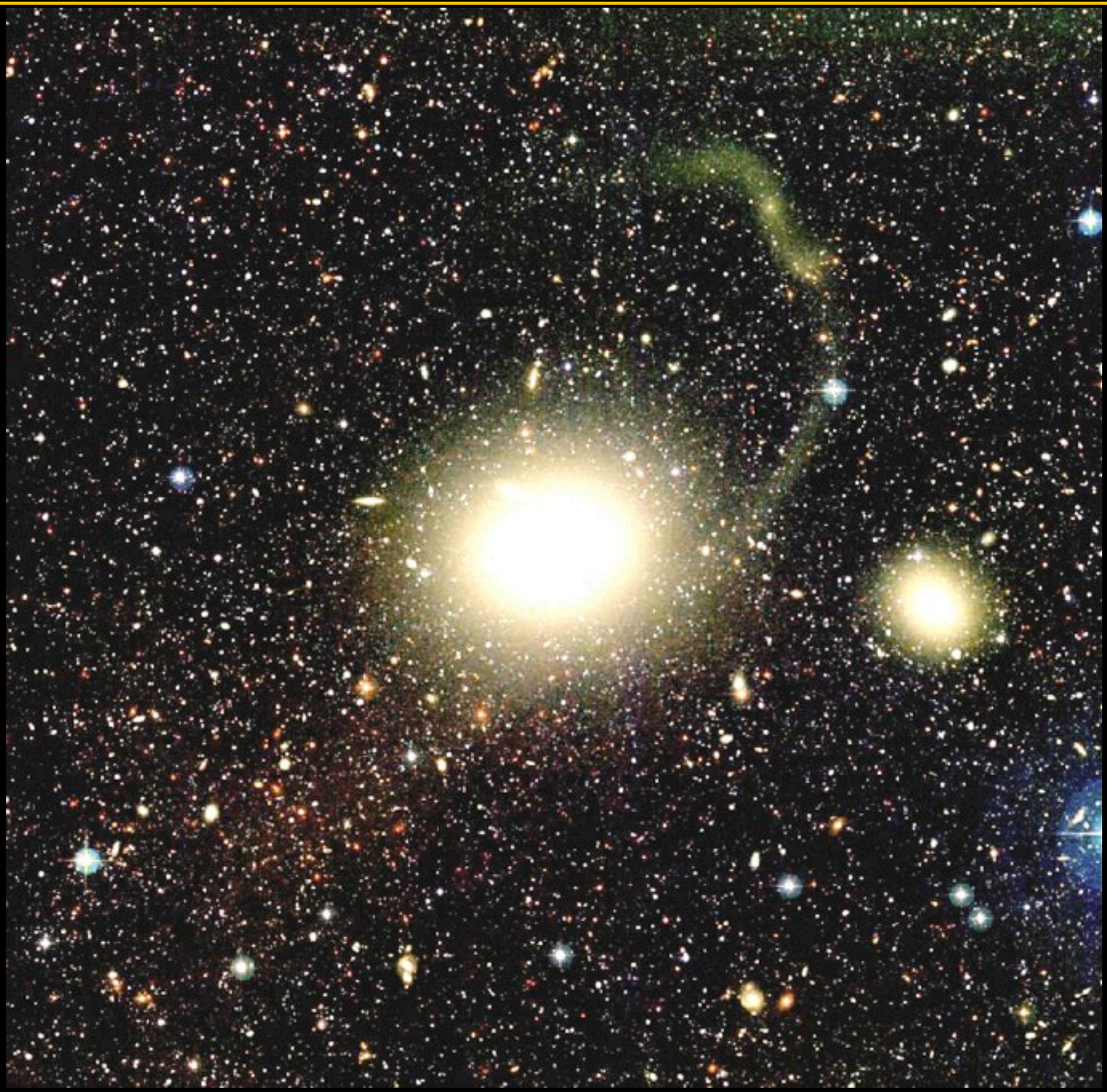
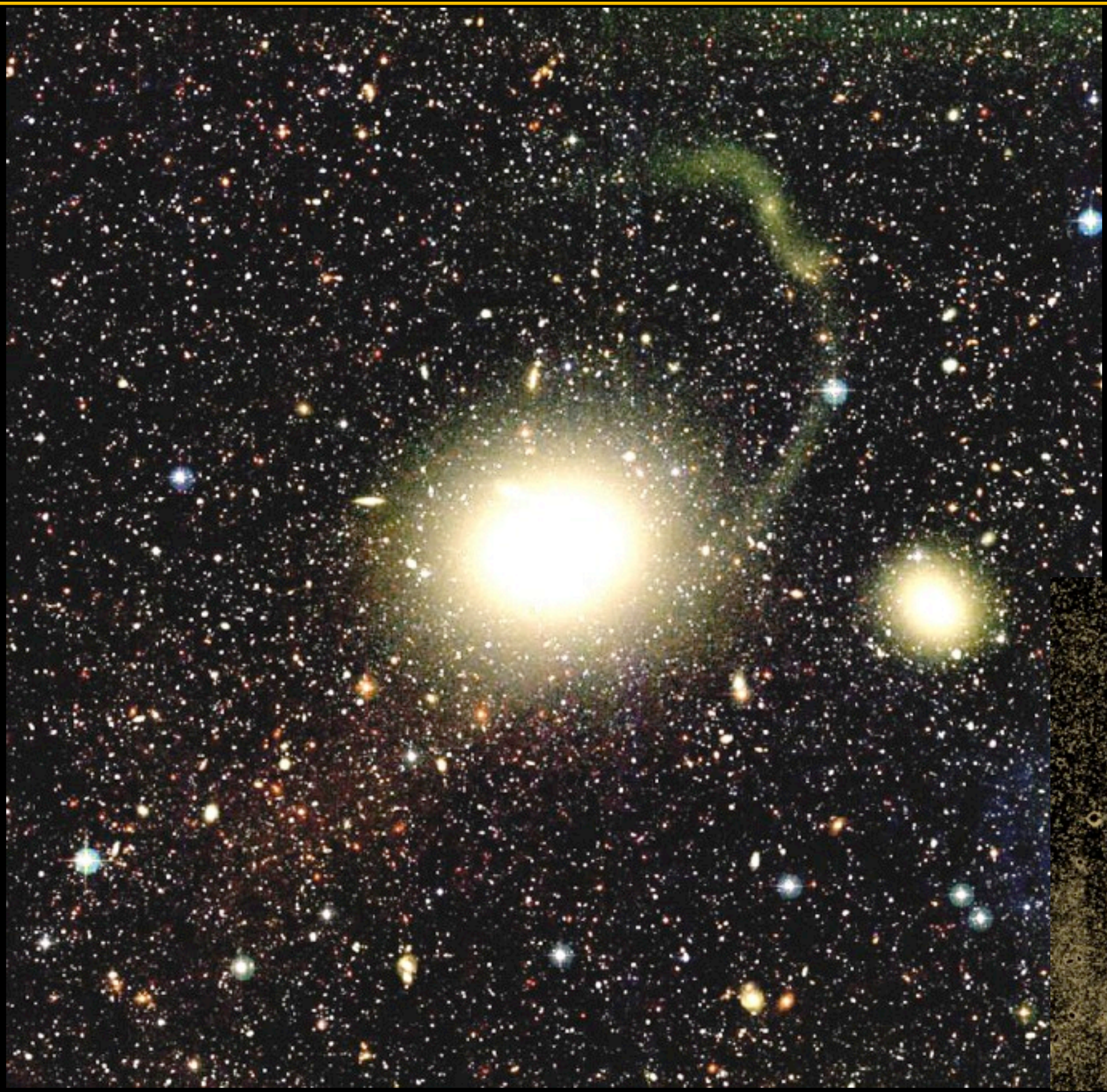
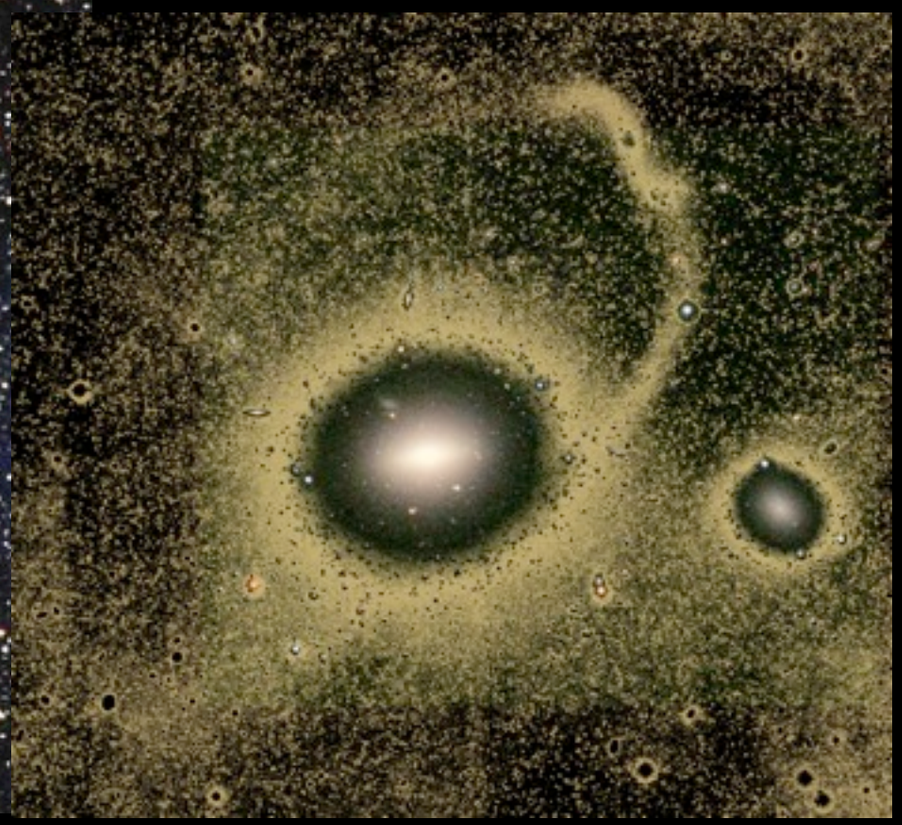


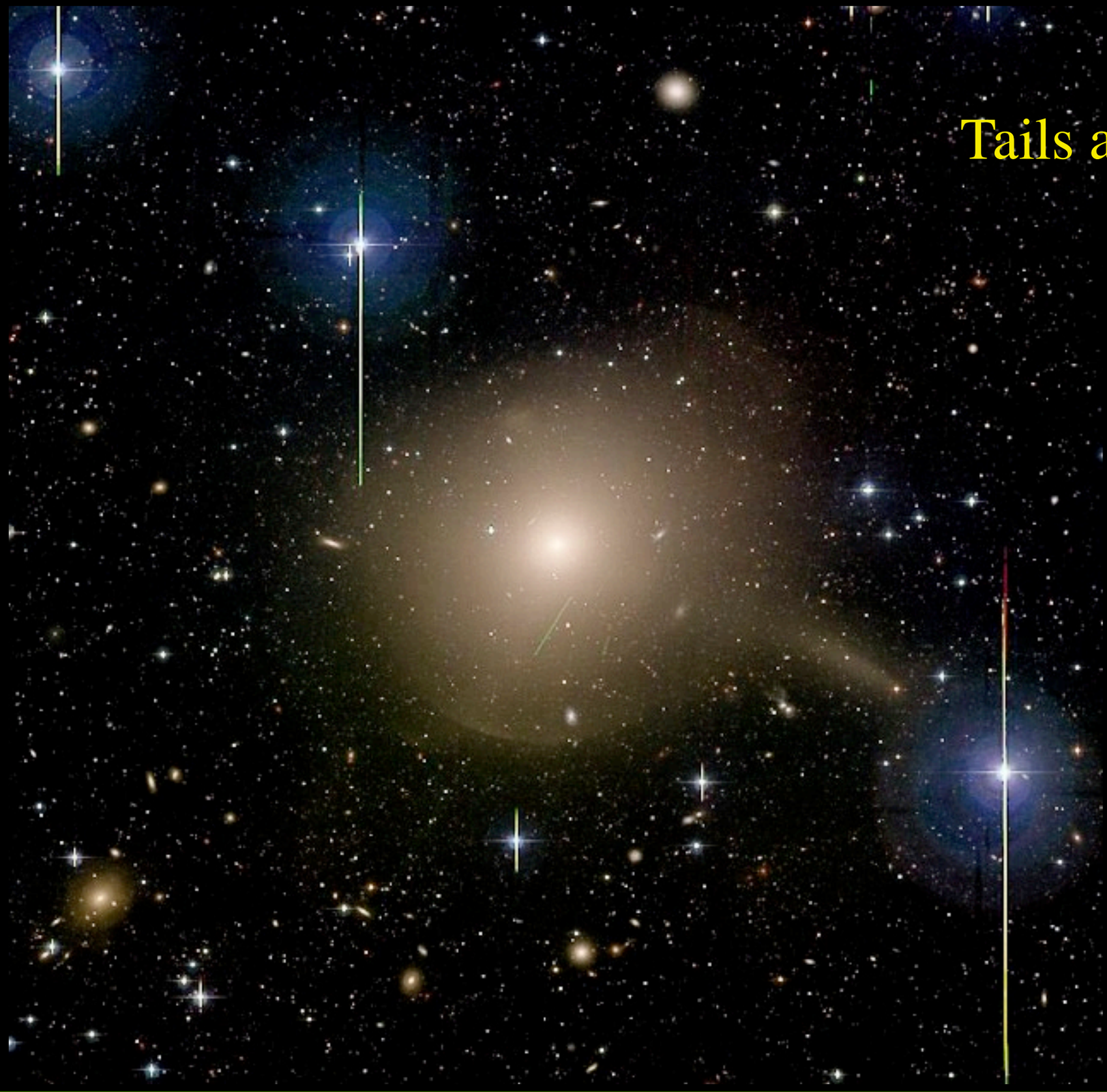


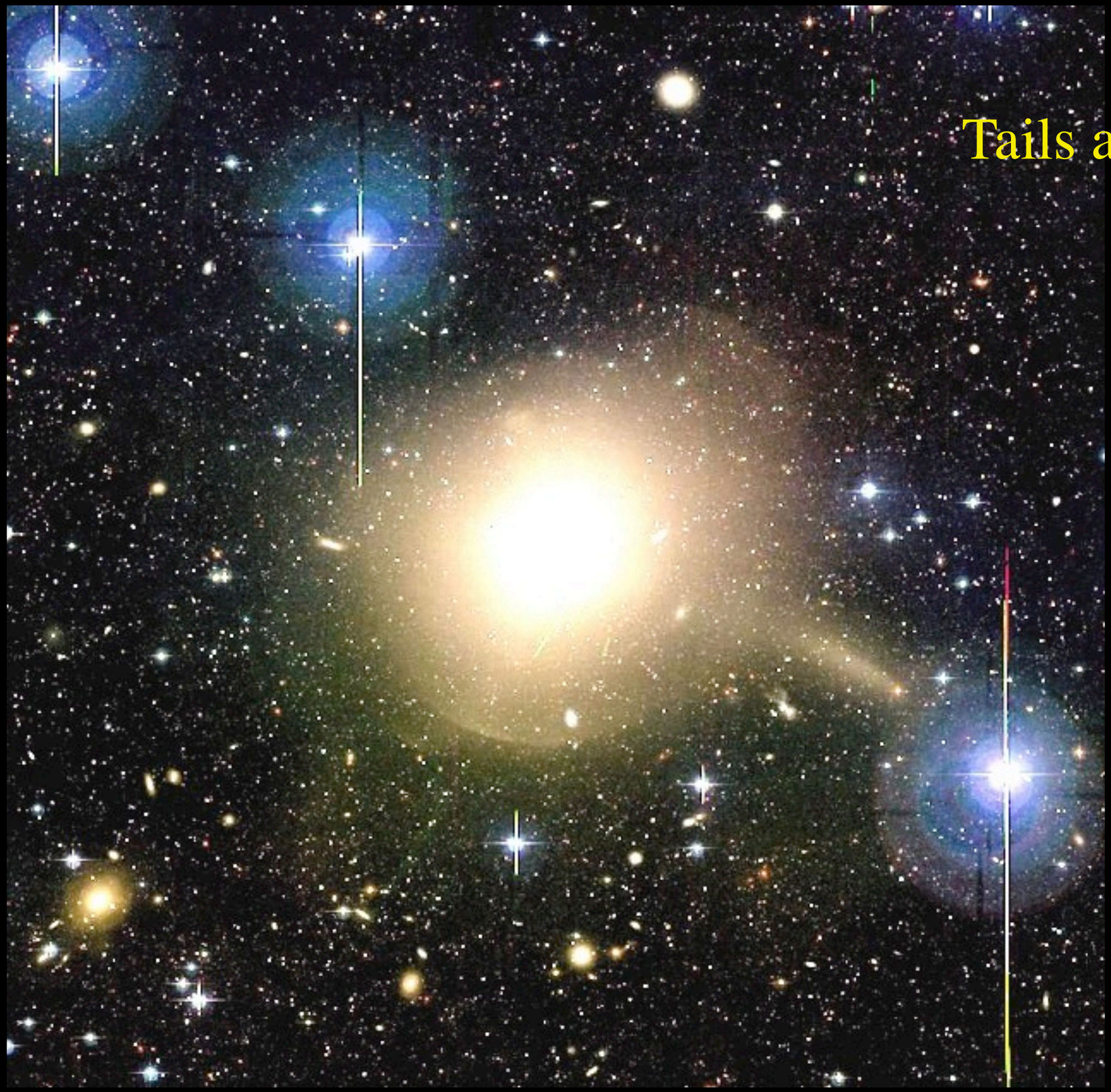
Tails and streams

Tails and streams






Tails and streams
Shells



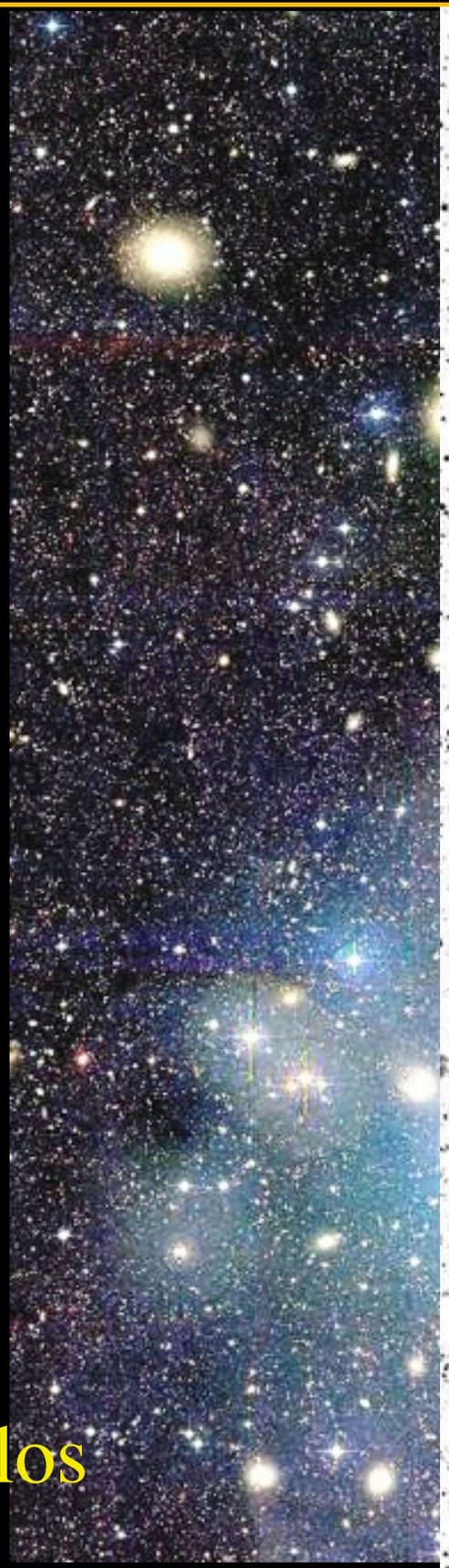
Tails and streams

Shells

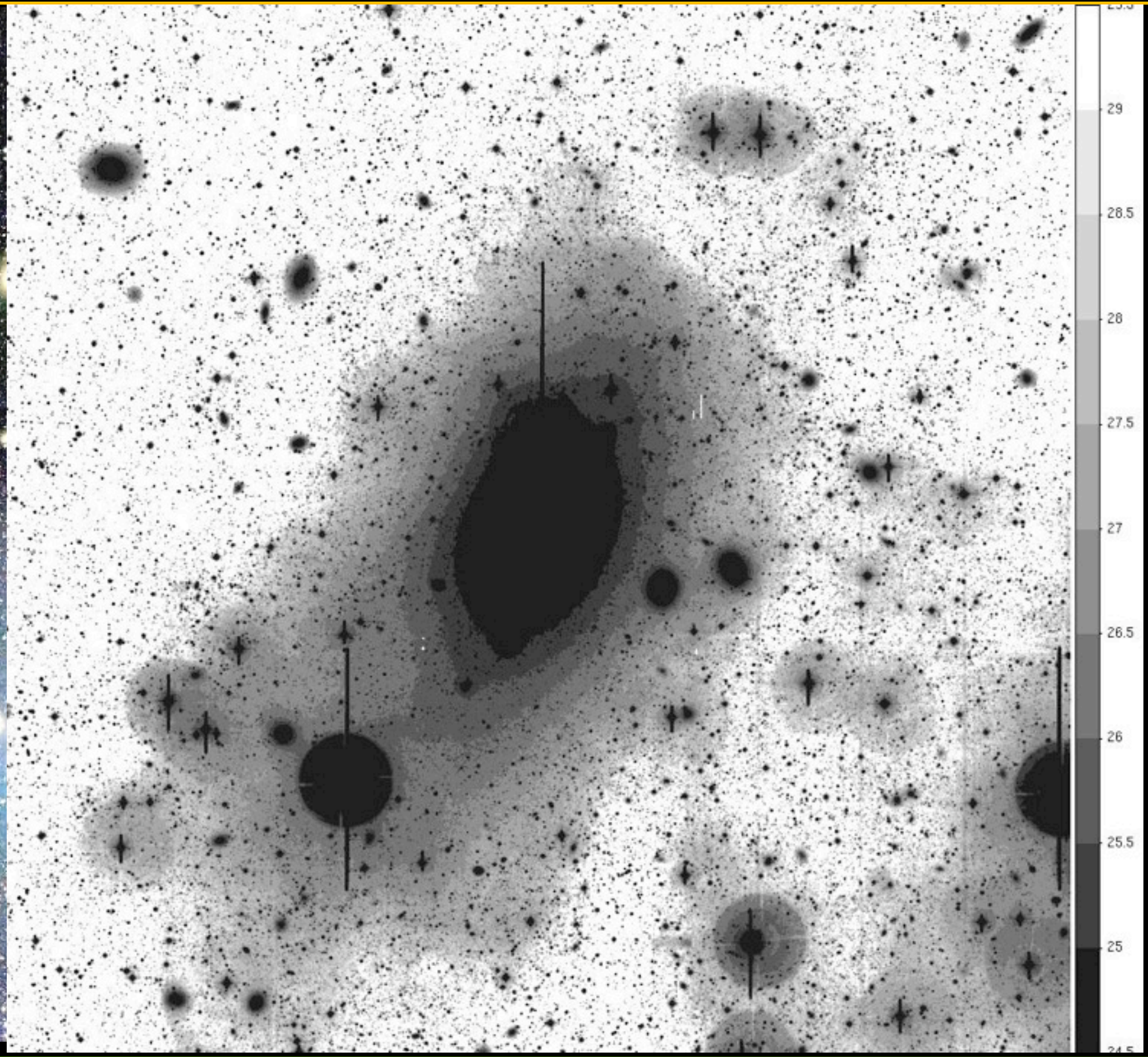
# NGC 4486 (M87) - NGVS

Halos

# NGC 4486 (M87) - NGVS



Halos

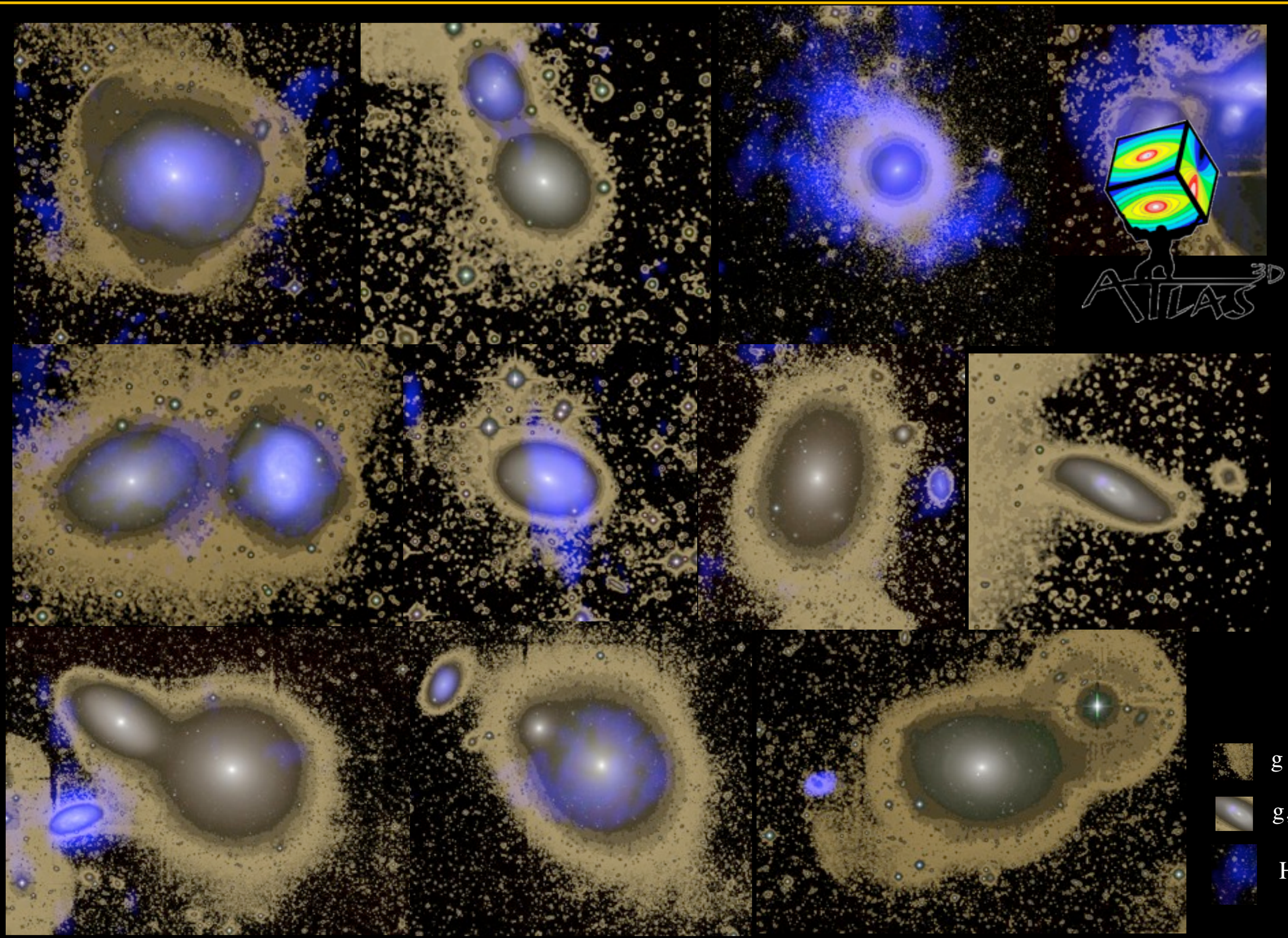


NGC 4477 NGC 4596 NGC 4608

Central bars

Boring, relaxed...

# Deep imaging of field Early-Type Galaxies



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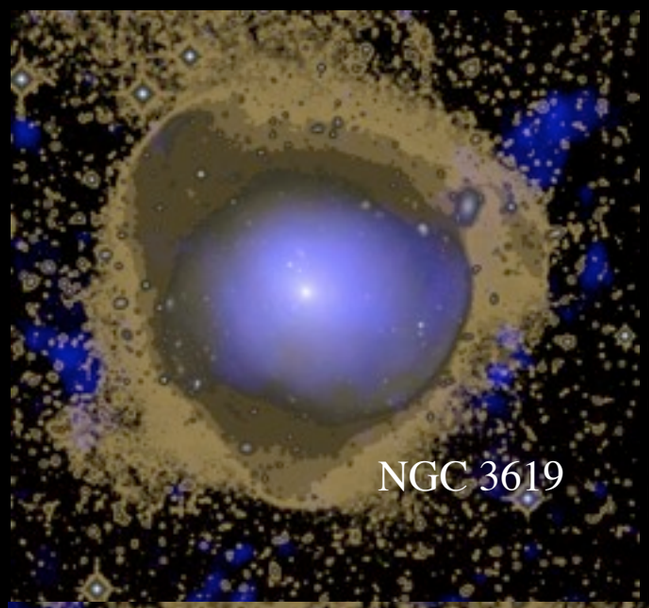
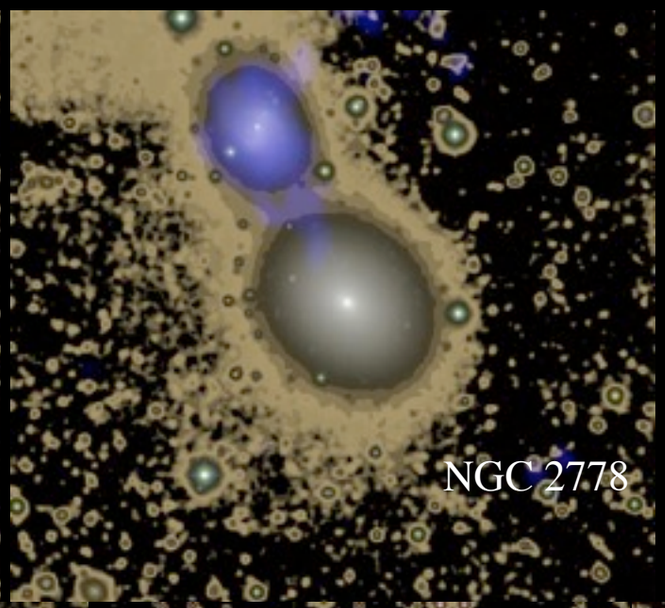
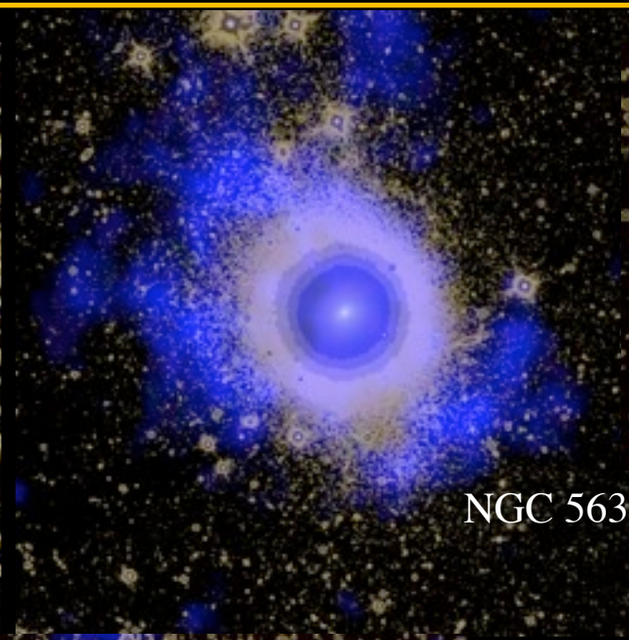
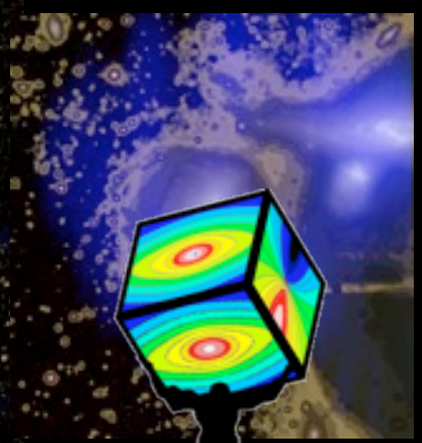
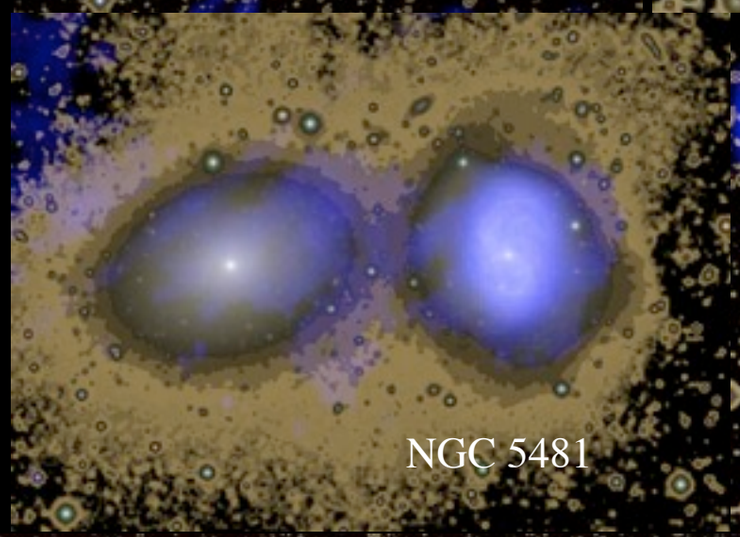
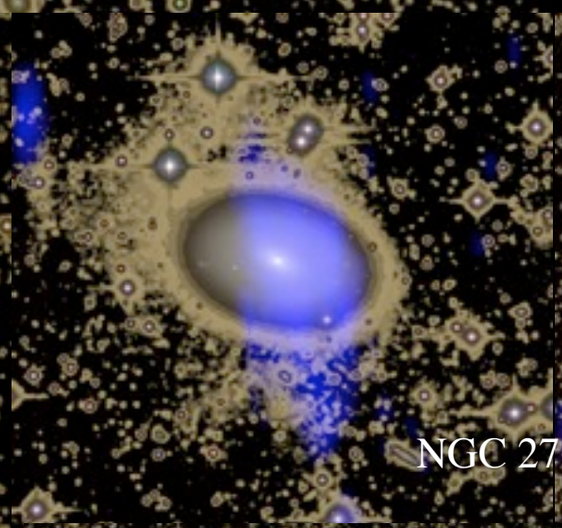

NGC 3619

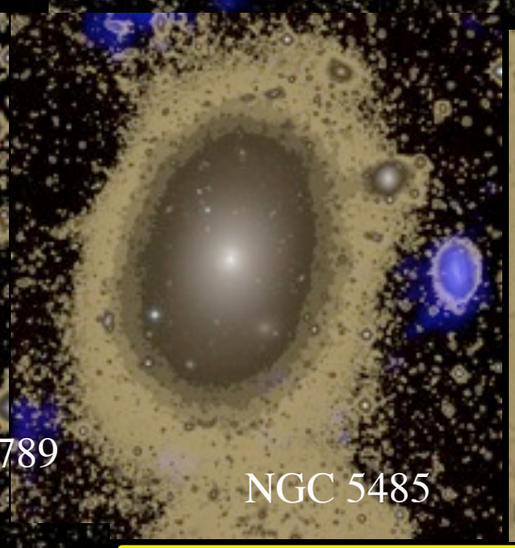

NGC 2778

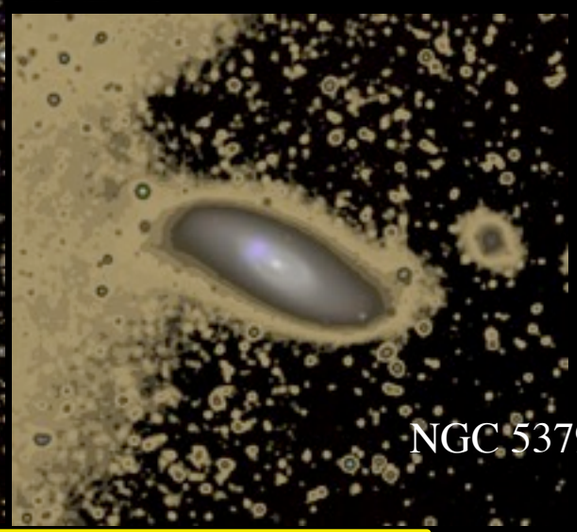

NGC 5631

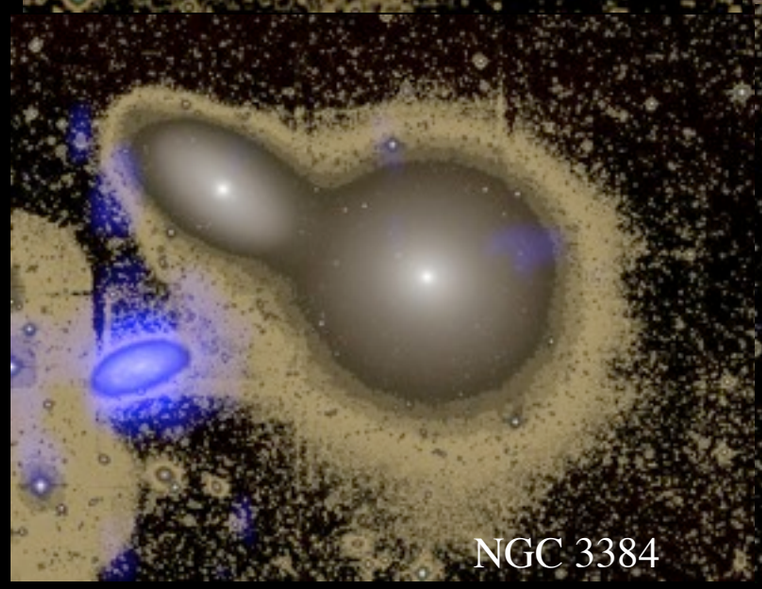

NGC 7463

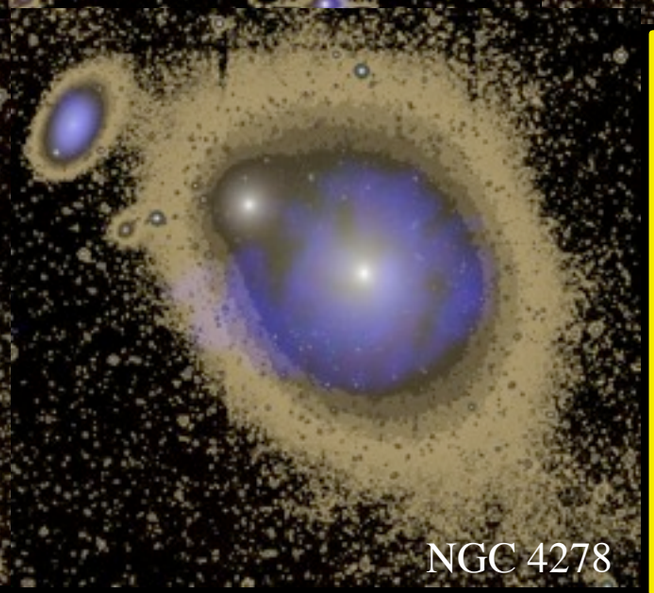

NGC 5481

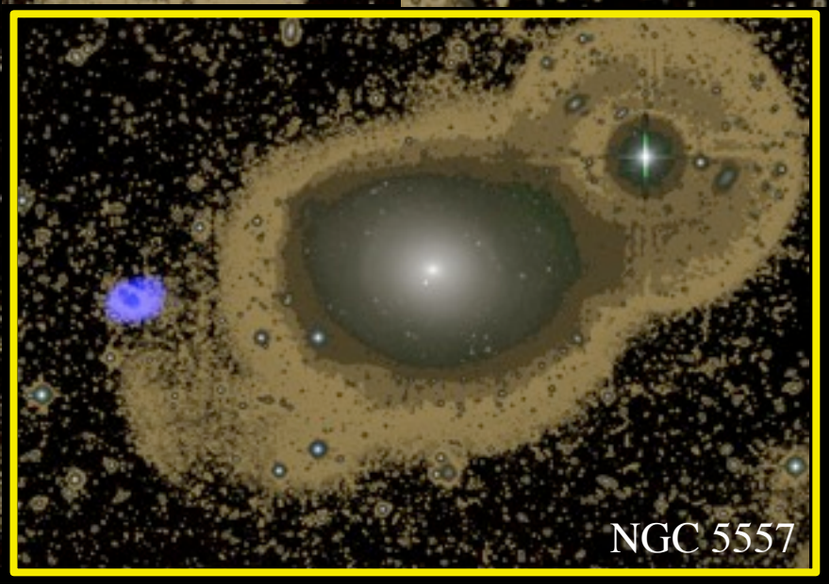

NGC 2789


NGC 5485

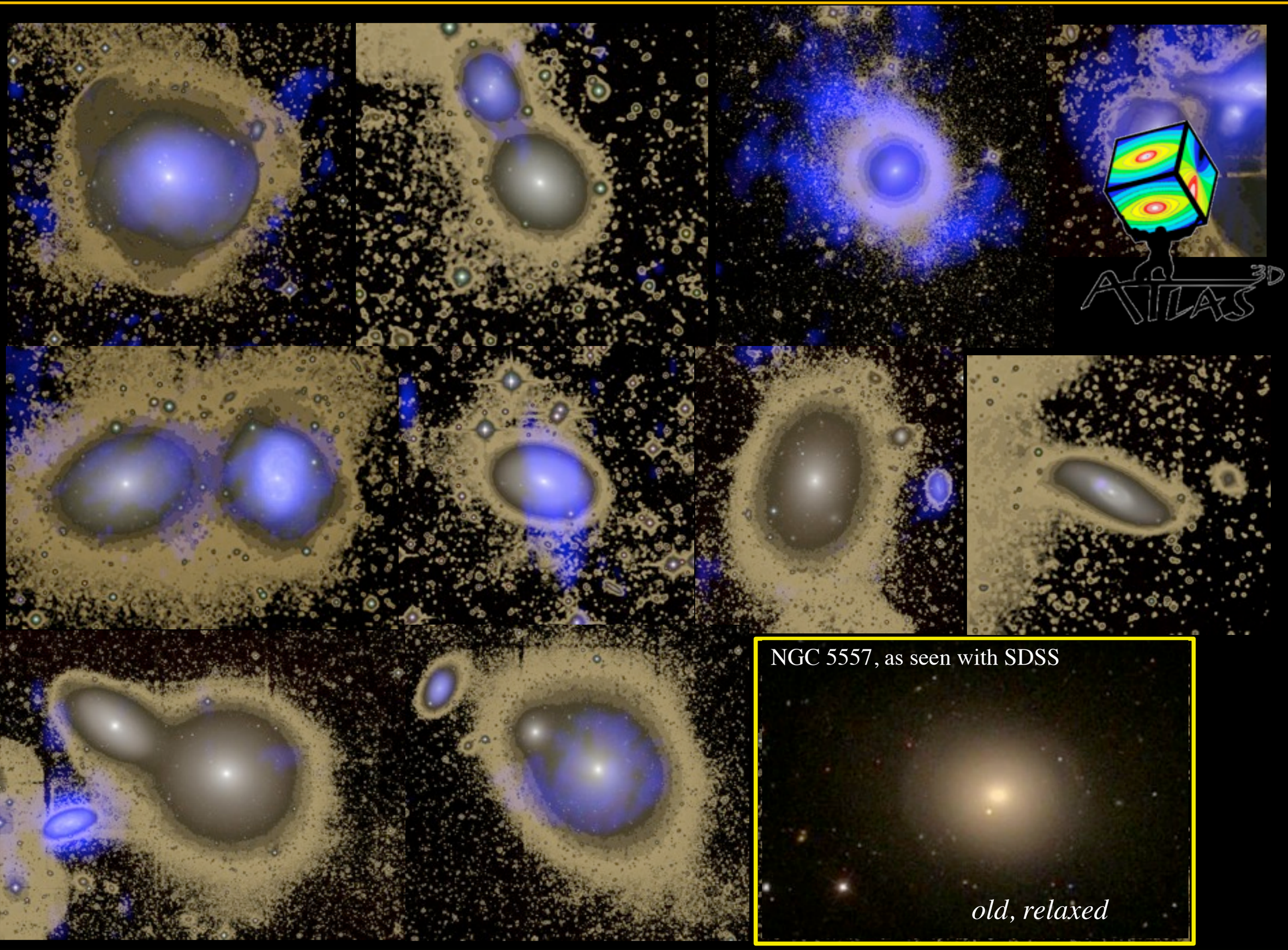

NGC 5379


NGC 3384


NGC 4278


NGC 5557

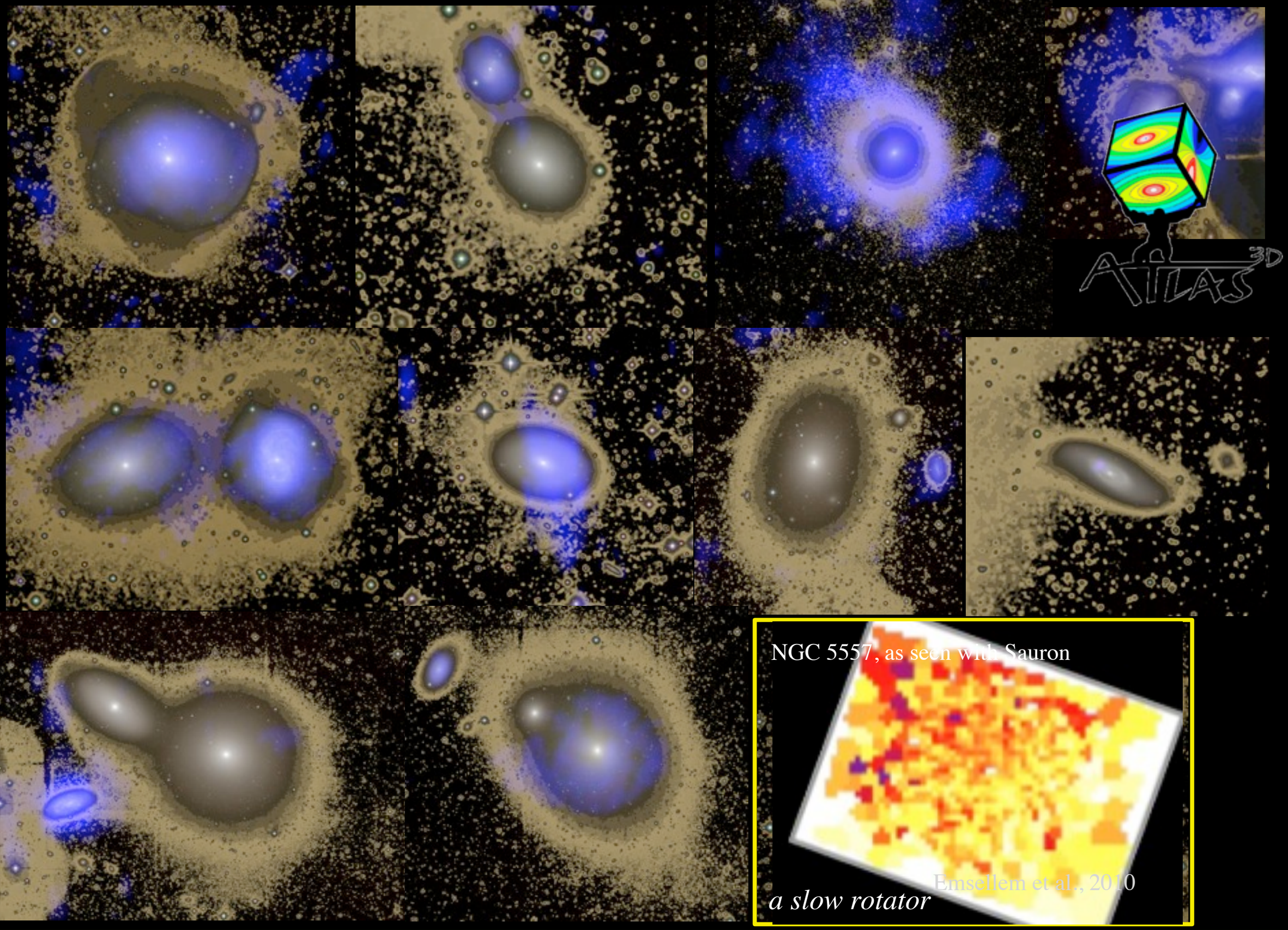
# Deep imaging of field Early-Type Galaxies



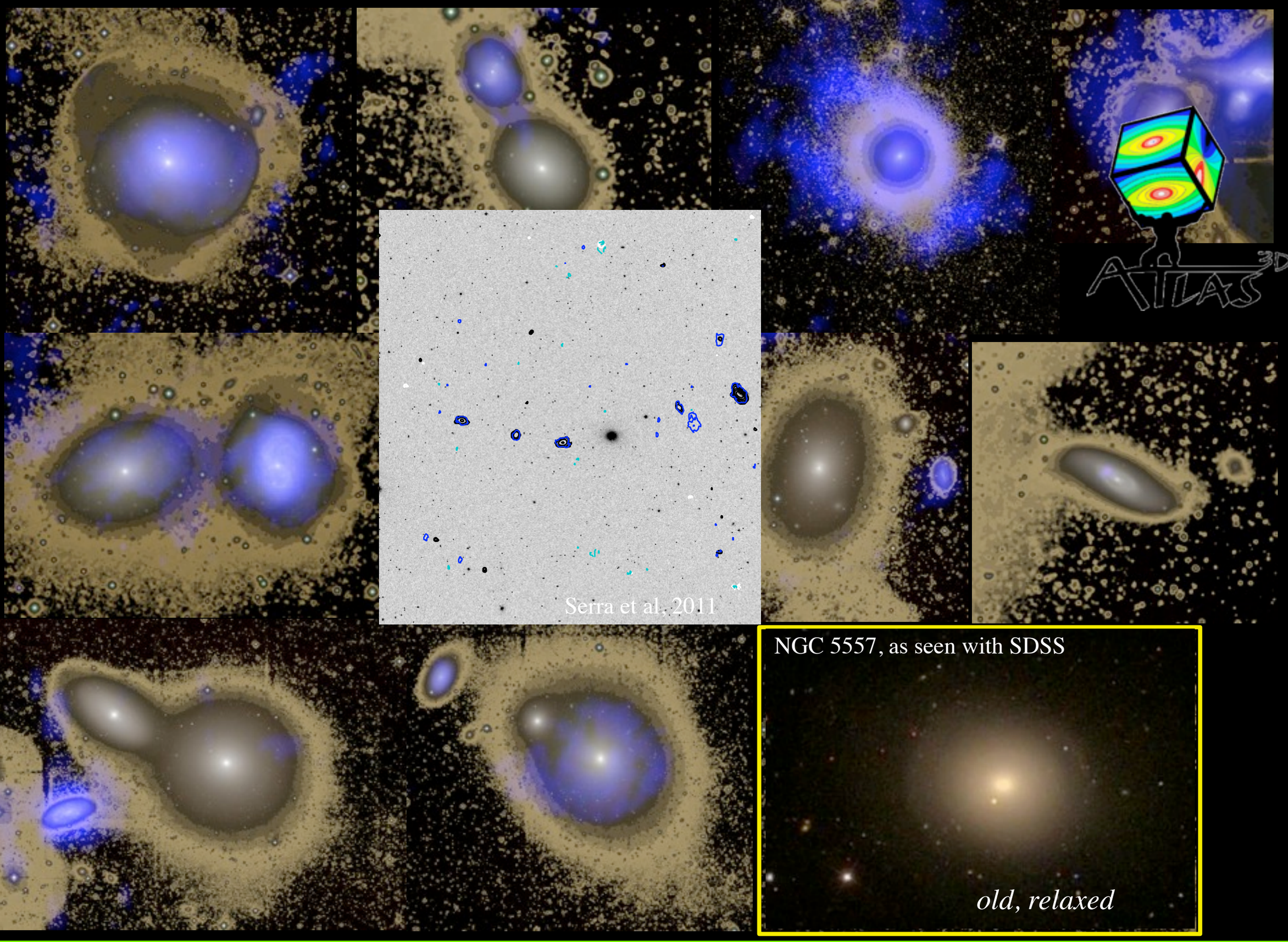

NGC 5557, as seen with SDSS

*old, relaxed*

# MegaCam observations of a sample of Atlas-3D galaxies



# MegaCam observations of a sample of Atlas-3D galaxies... with extended HI



# NGC 5557 as seen by MegaCam

Duc et al., 2010

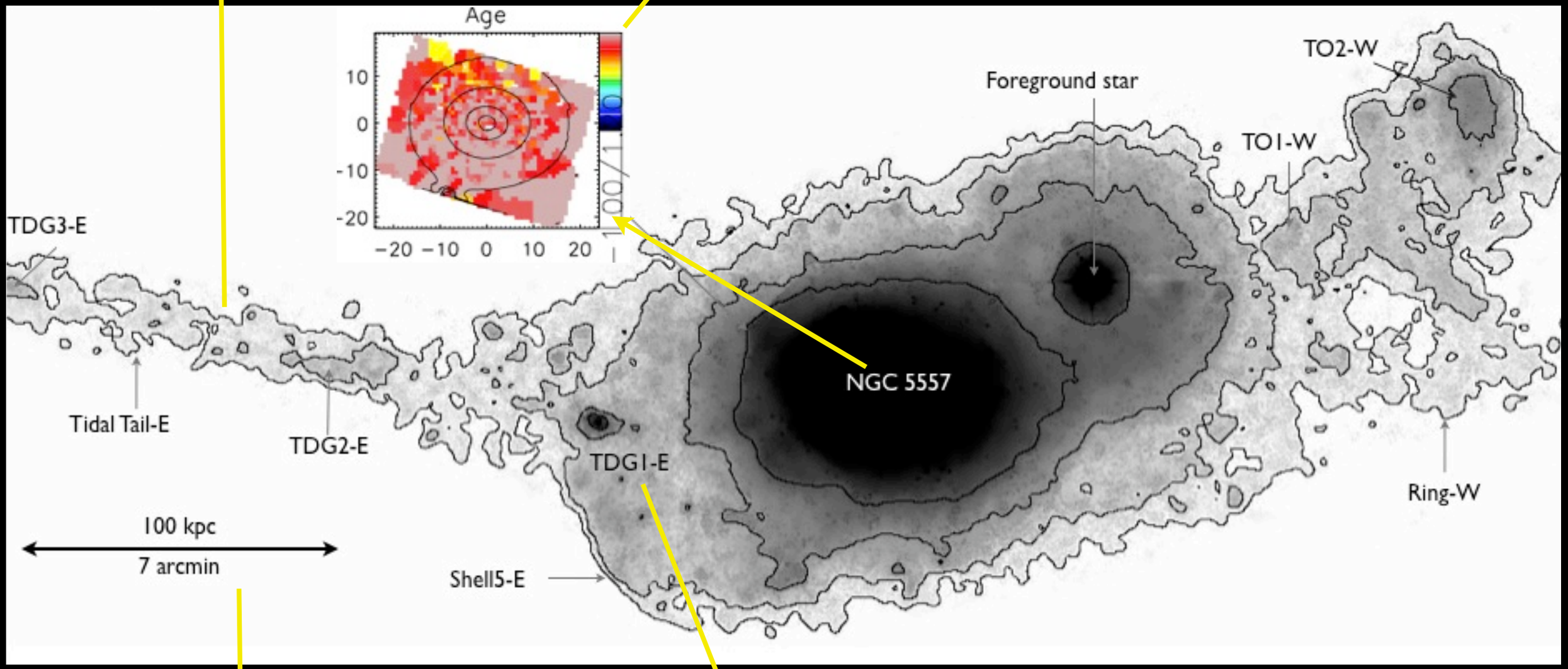
# NGC 5557 as seen by MegaCam + WSRT/HI

Duc et al., 2011

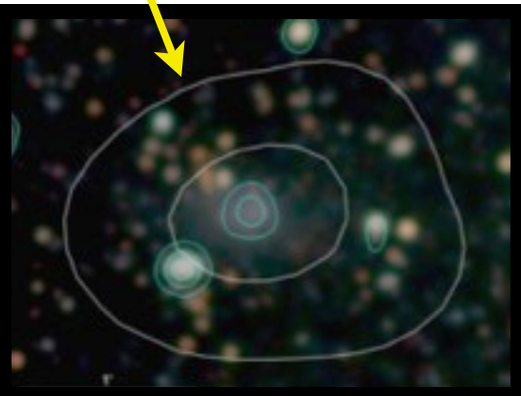
# NGC 5557: an old major merger

the tidal tails reveal a wet
relatively recent major merger
et the originof the ETG

the absence of young stars / gas
in the remnant tell that the
merger is at least 1-2 Gyr old

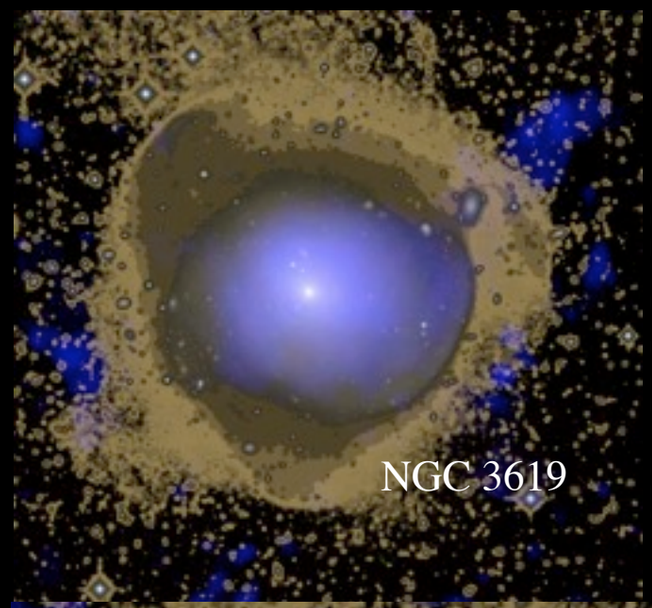


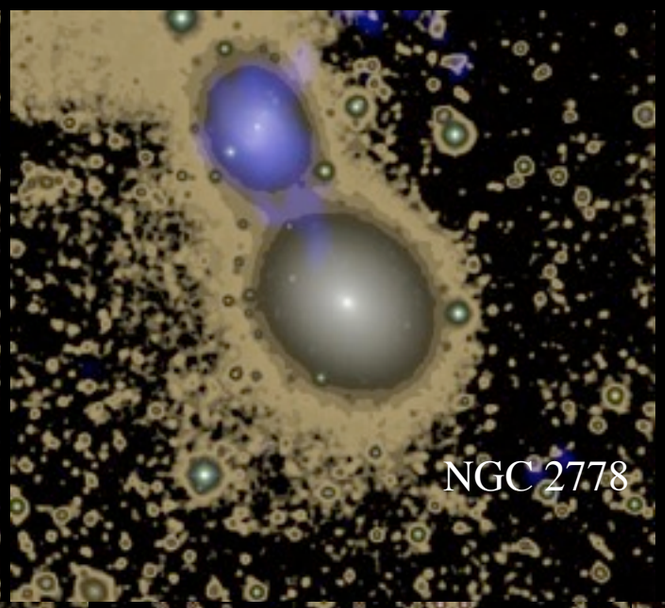

one of the largest stellar
structure known in the
nearby Universe

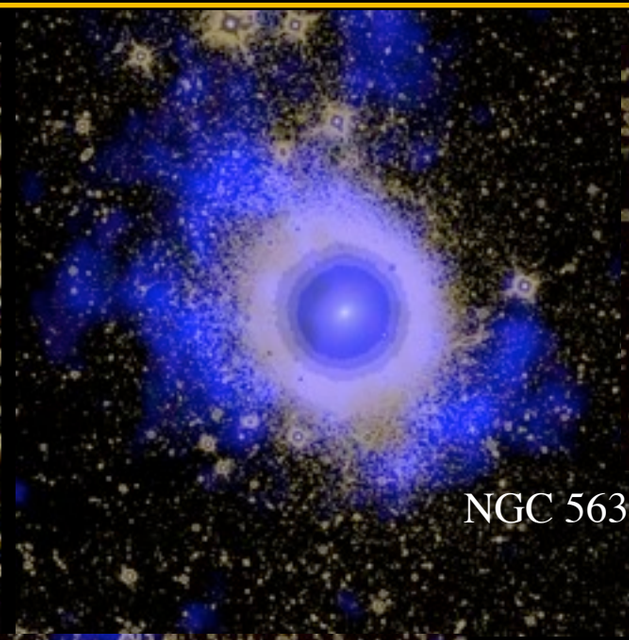


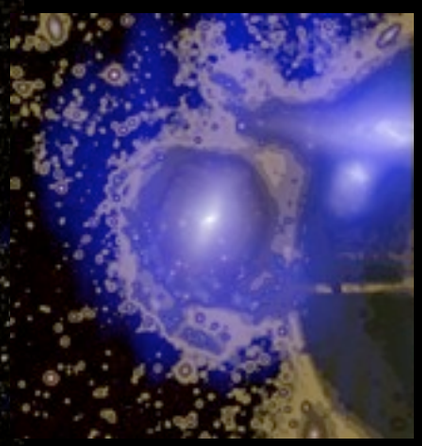
one of the oldest
surviving Tidal Dwarf Galaxy
so far know

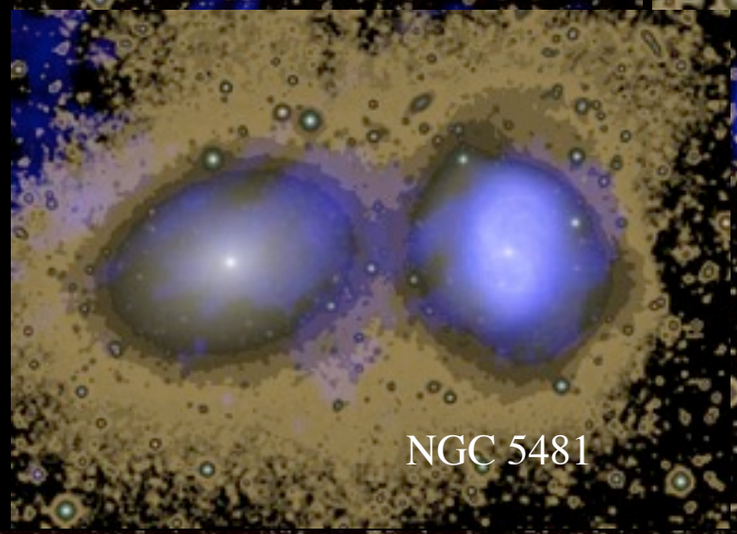
# MegaCam observations of a sample of Atlas-3D galaxies

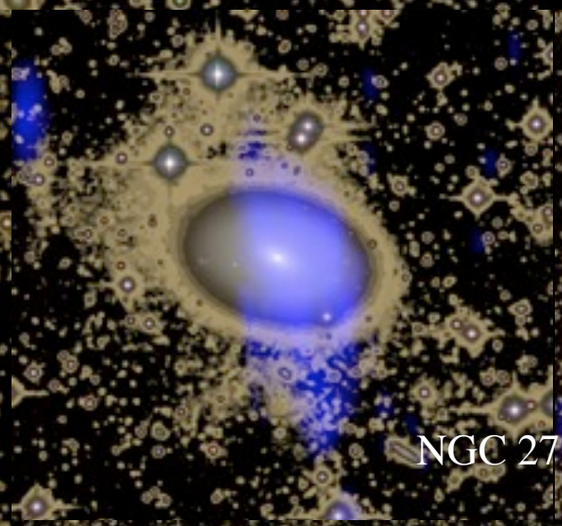

NGC 3619

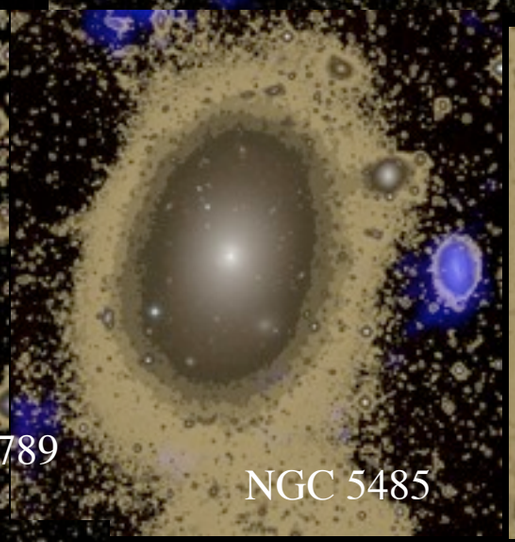

NGC 2778

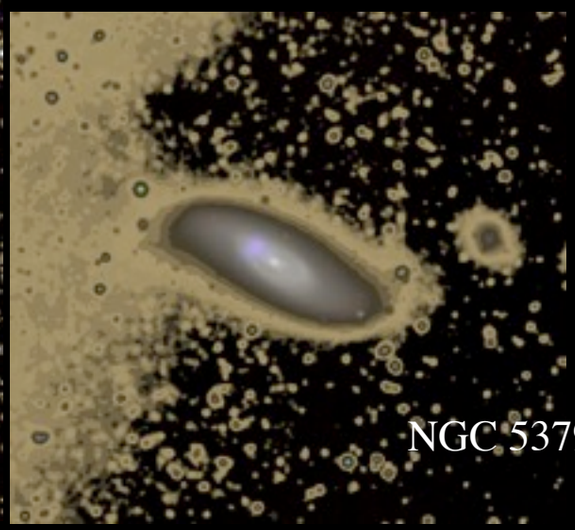

NGC 5631

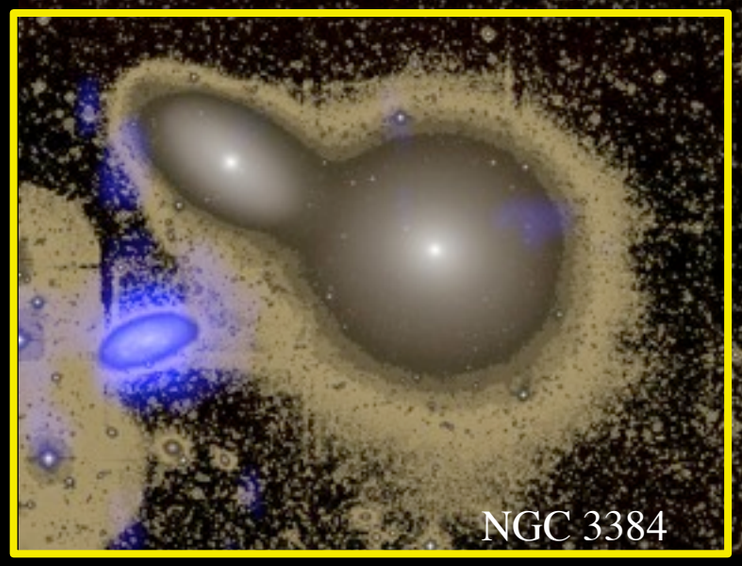

NGC 7465

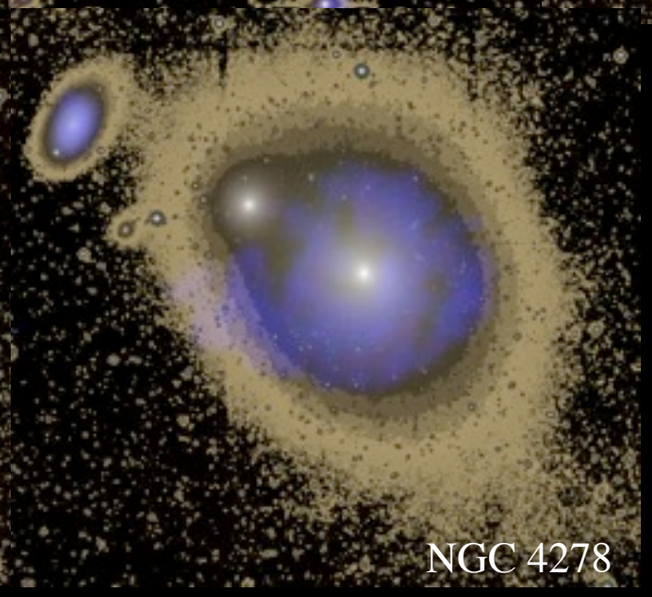

NGC 5481

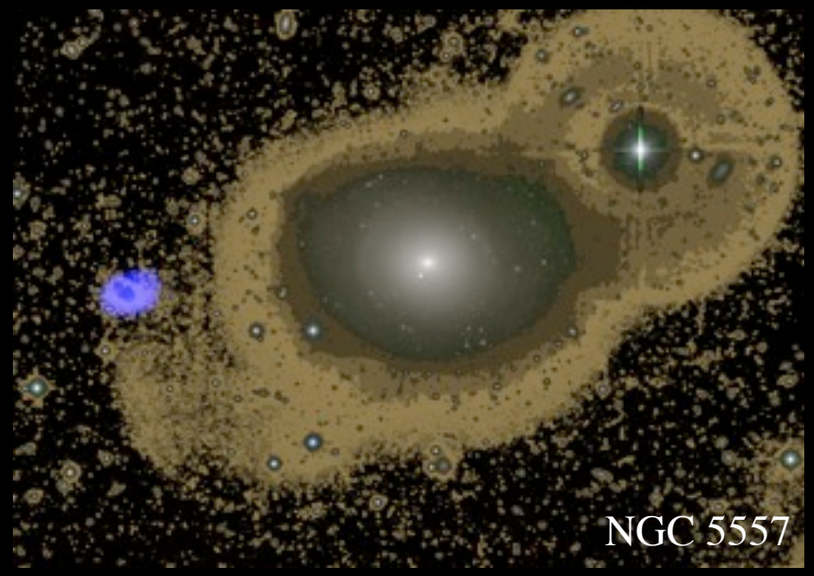

NGC 2789


NGC 5485

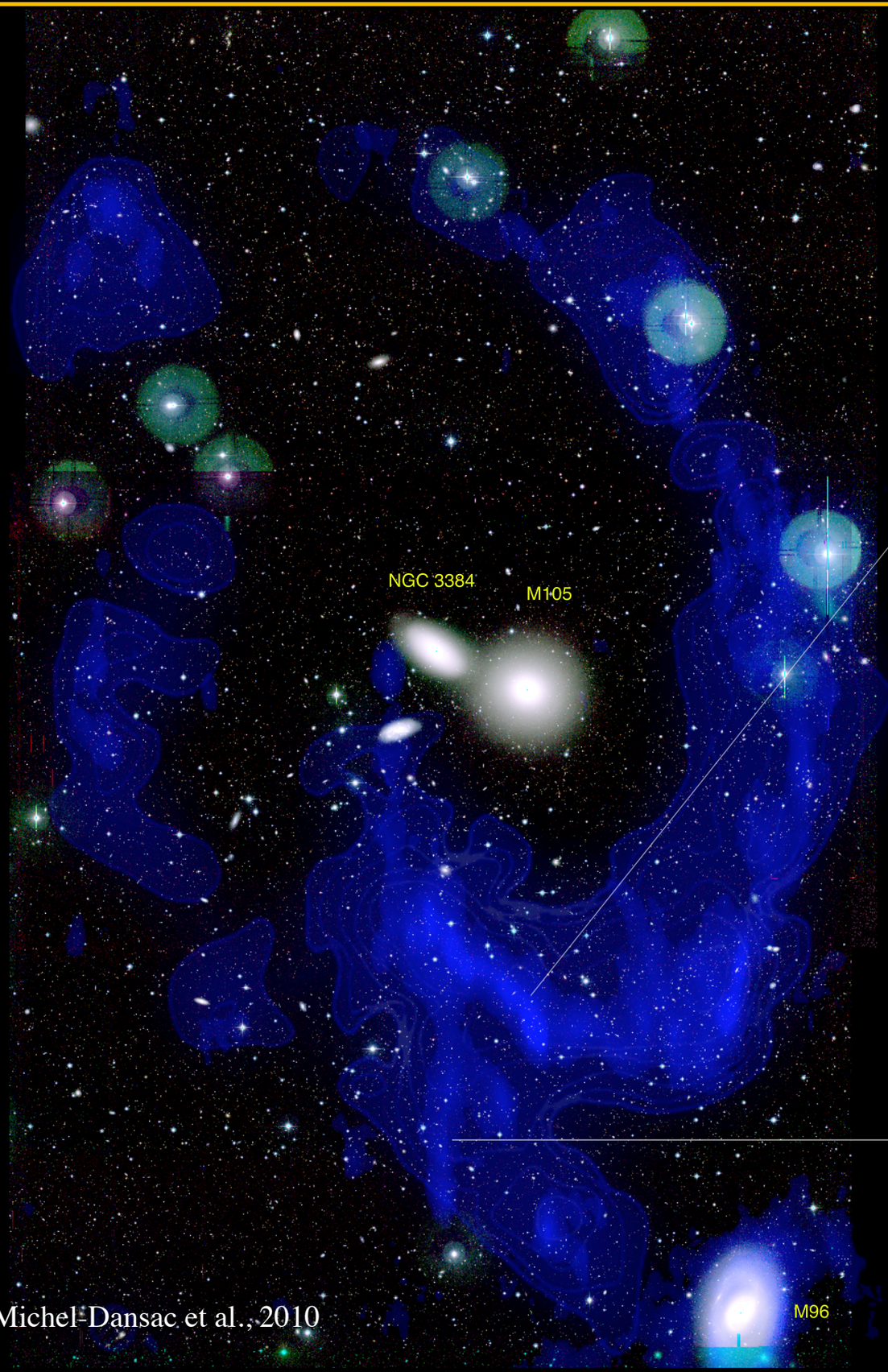

NGC 5379


NGC 3384

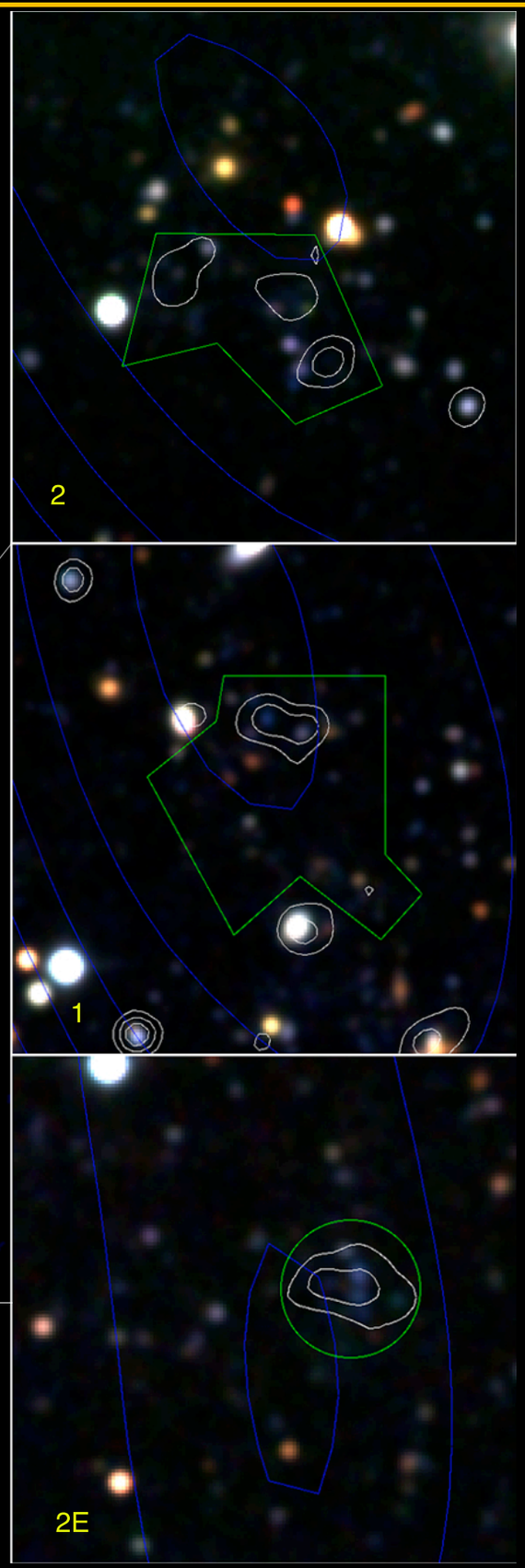

NGC 4278


NGC 5557

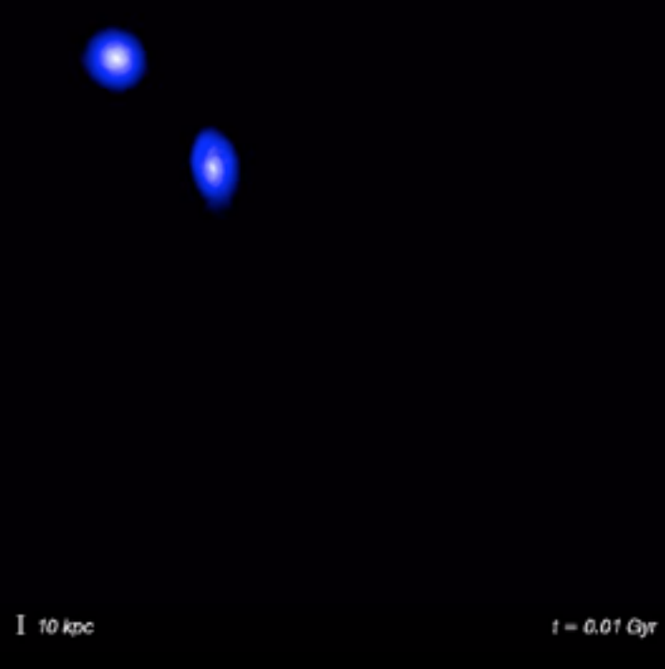
# NGC 3384: a collisional origin for the Leo Ring



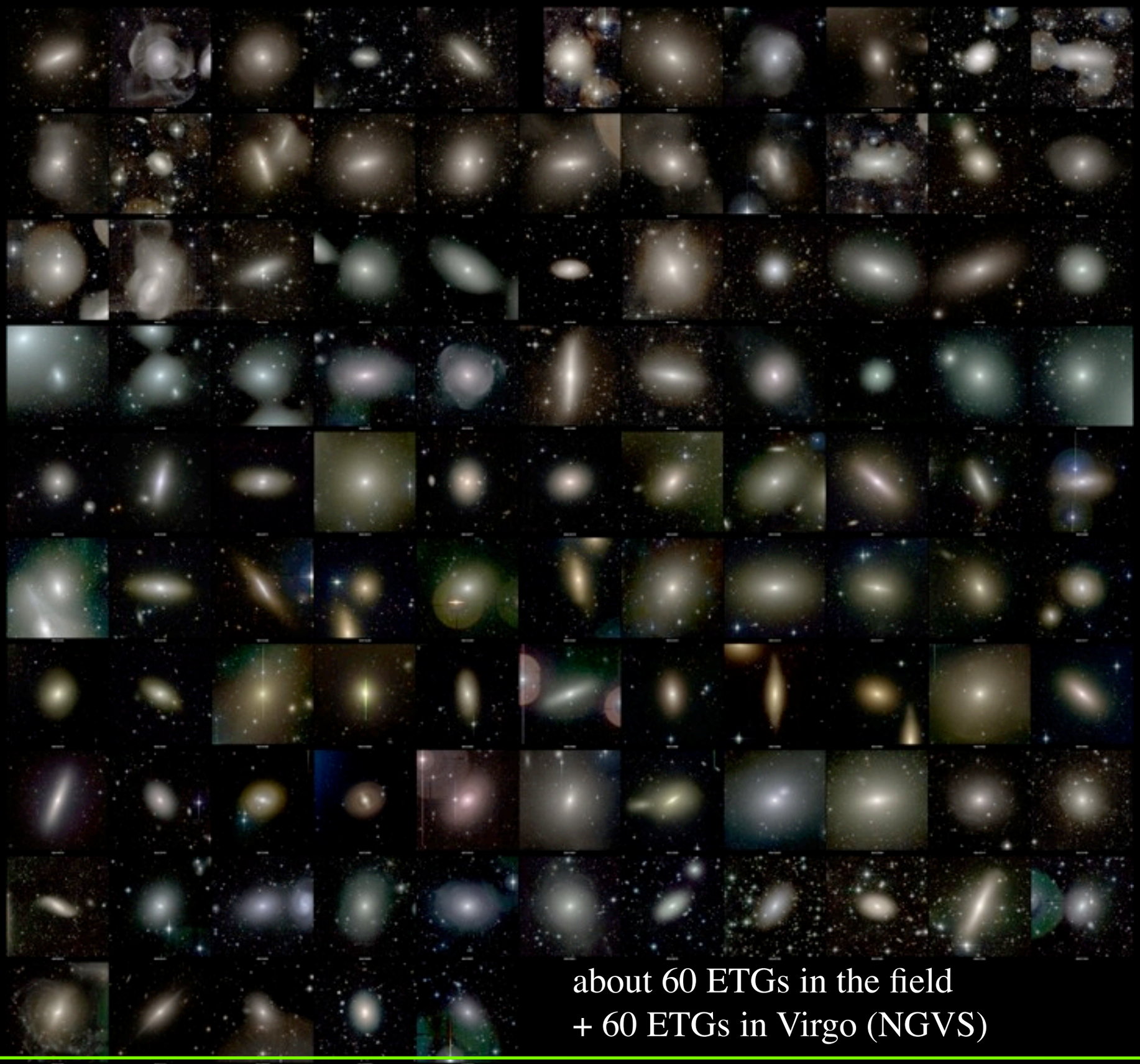

Michel-Dansac et al., 2010




- The gas in the Leo Ring is not primordial
- Young stars along it detected for the first time in the optical with MegaCam



# Fine structures in the field vs in clusters



about 60 ETGs in the field
+ 60 ETGs in Virgo (NGVS)

# Fine structures in the field vs NGVS

*Systematic differences*

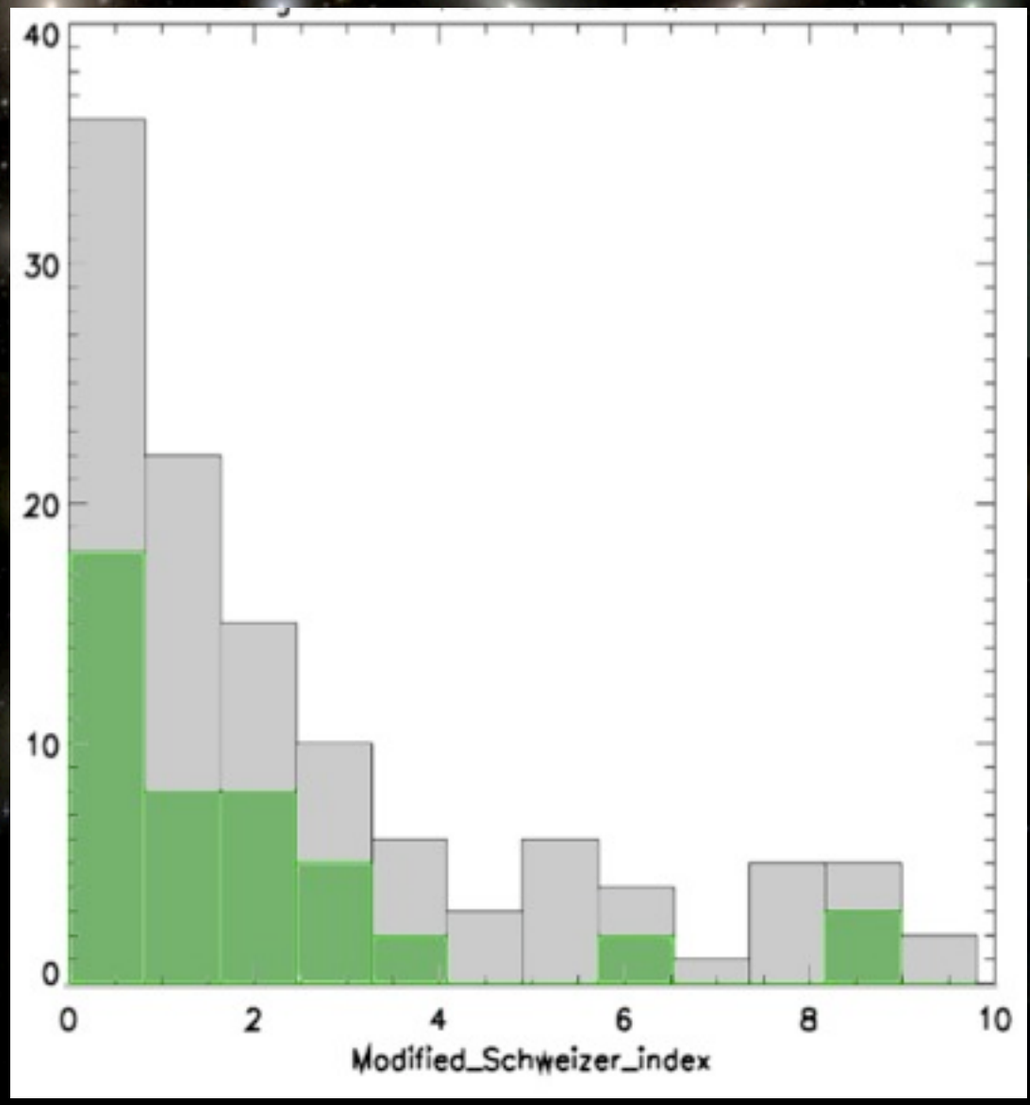
- Fraction of fully relaxed ETGs slightly higher among Virgo ETGs
- Fraction of highly perturbed ETGs higher in the «field»

✓Age effect: cluster ETGs are older, and the memory of their past mass accretion has been lost

✓History effect: the mass assembly is different in the field or clusters

✓Local environment effect: tails and fine structures are destroyed in clusters (contributing to the ICL)

Statistical significance of these results?



# A minor/major wet/dry orgin for ths ETG ????