A visualization of the cosmic web, showing a complex network of filaments and clusters of galaxies. The filaments are depicted as thin, glowing purple and blue lines, while the clusters are represented by denser regions of orange and yellow points. A horizontal scale bar is positioned in the upper center of the image.

31.25 Mpc/h

Astrophysics III

Formation and Evolution of galaxies

Michaela Hirschmann, Fall-Winter semester 2024

Lecture content and schedule

- *Chapter 1:* Introduction (galaxy definition, astronomical scales, observable quantities — repetition of Astro-I)
- *Chapter 2:* Brief review on stars
- *Chapter 3:* Radiation processes in galaxies and telescopes;
- *Chapter 4:* The Milky Way
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- *Chapter 7:* Black holes and active galactic nuclei
- *Chapter 8: Galaxies and their environment;*
- *Chapter 9:* High-redshift galaxies
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- *Chapter 17:* Modern simulations & future prospects

Part I:
Observational
basics & facts of
galaxies
first 7 lectures

Part II:
Theory & models
of
galaxy evolution
processes
second 7 lectures

Outline of Chapter 8



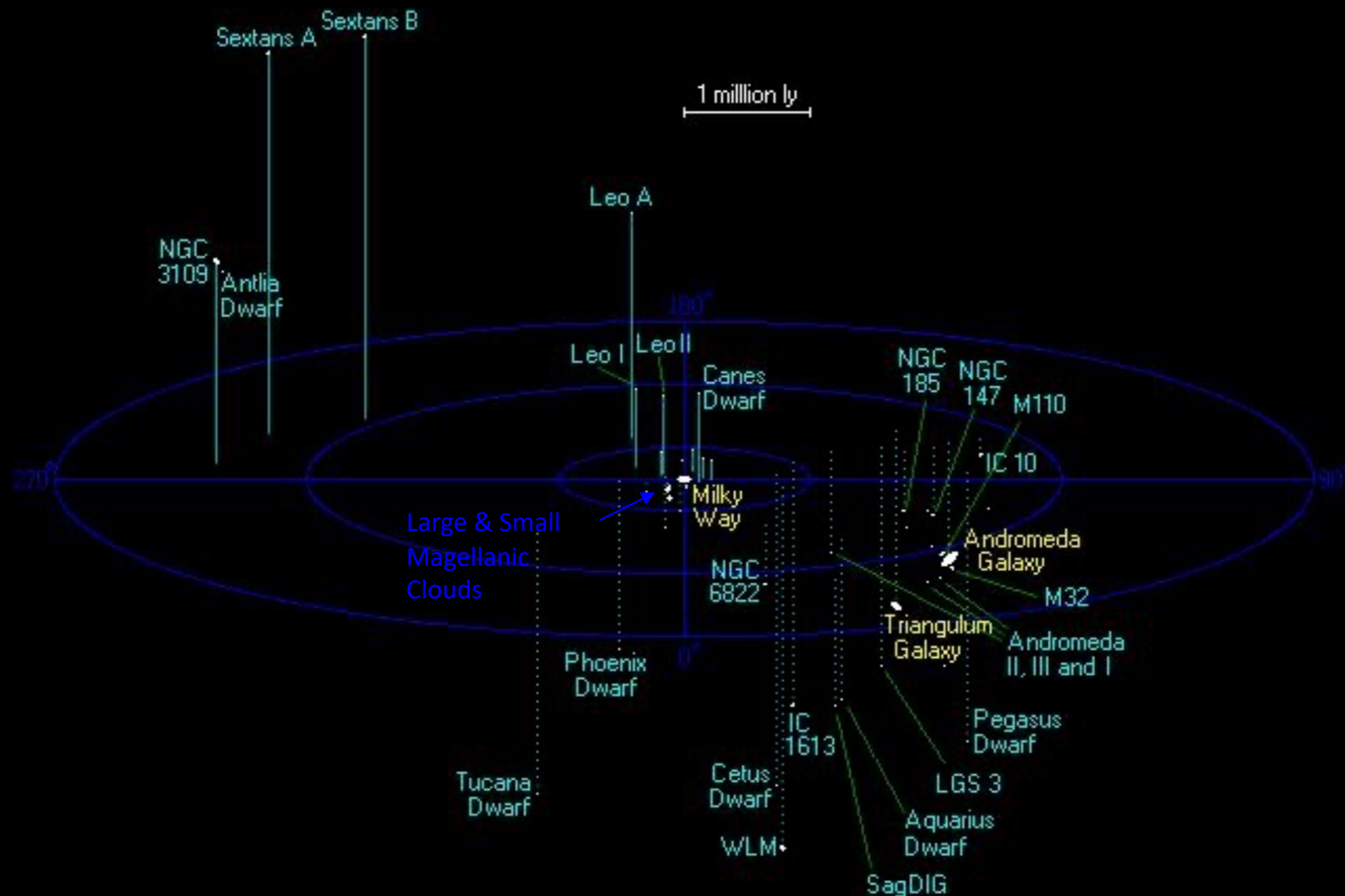
- Galaxies and their environment
 - Groups of galaxies
 - Clusters of galaxies

Galaxy Groups

- contain ~2-50 “giant” galaxies (plus a contingent of dwarfs)
- $M_{\text{tot}} \sim \text{few } 10^{12} - \text{few } 10^{13} M_{\text{sun}}$
- velocity dispersion $\sigma \sim 100 - 500 \text{ km/s}$
- about half have detectable X-ray halos of hot gas, enriched to a few tenths Z_{sun}
- $(M/L) \sim 80 - 300 M_{\text{sun}}/L_{\text{sun}}$

Galaxy environments — Groups

The Local Group



Galaxy environments — Groups

Irregular galaxies in the Local Group: the LMC and SMC



Large Magellanic Cloud

1 million ly

Leo A

160°

Leo II

NGC 1300

Phoenix Dwarf

Tucana Dwarf

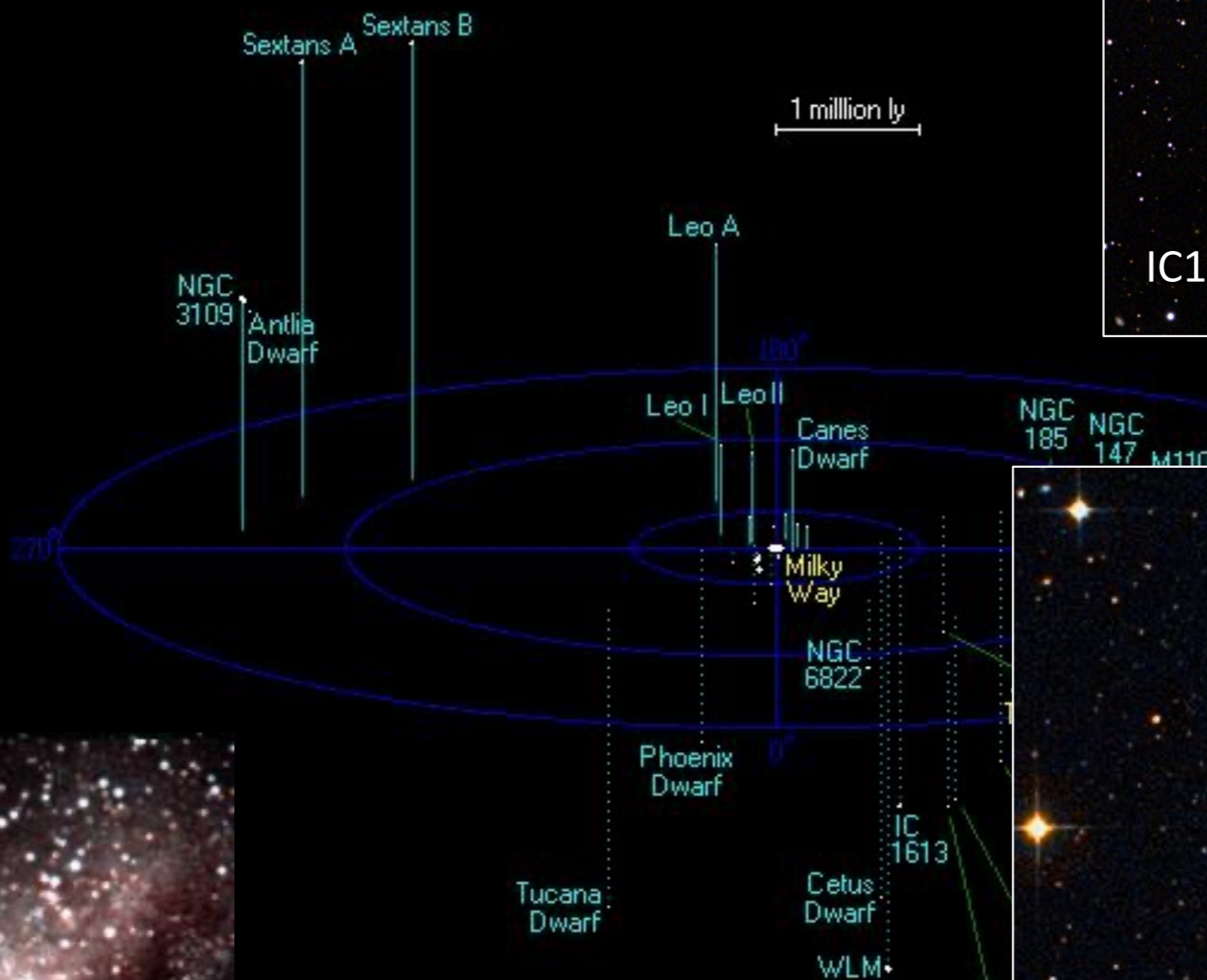


Small Magellanic Cloud

© Stéphane Cuisard

Galaxy environments — Groups

dwarf Irr



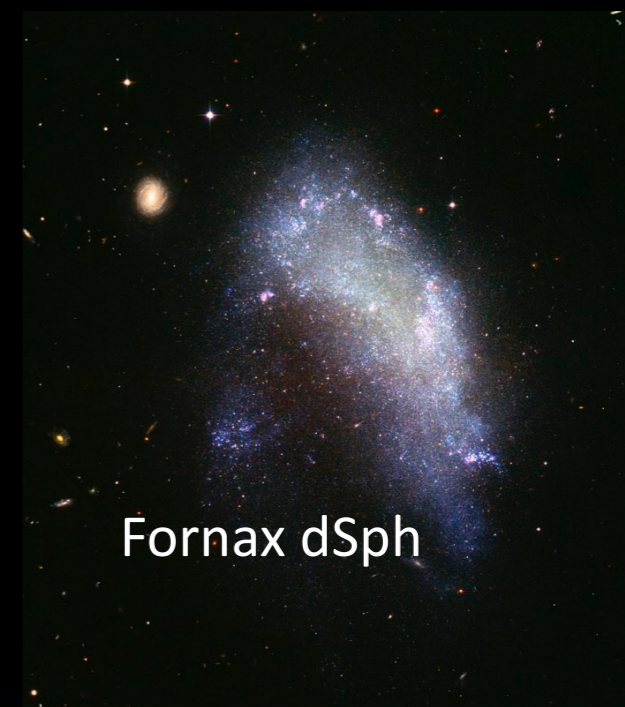
IC10



Galaxy environments — Groups



dwarf ellipticals &
dwarf spheroidals

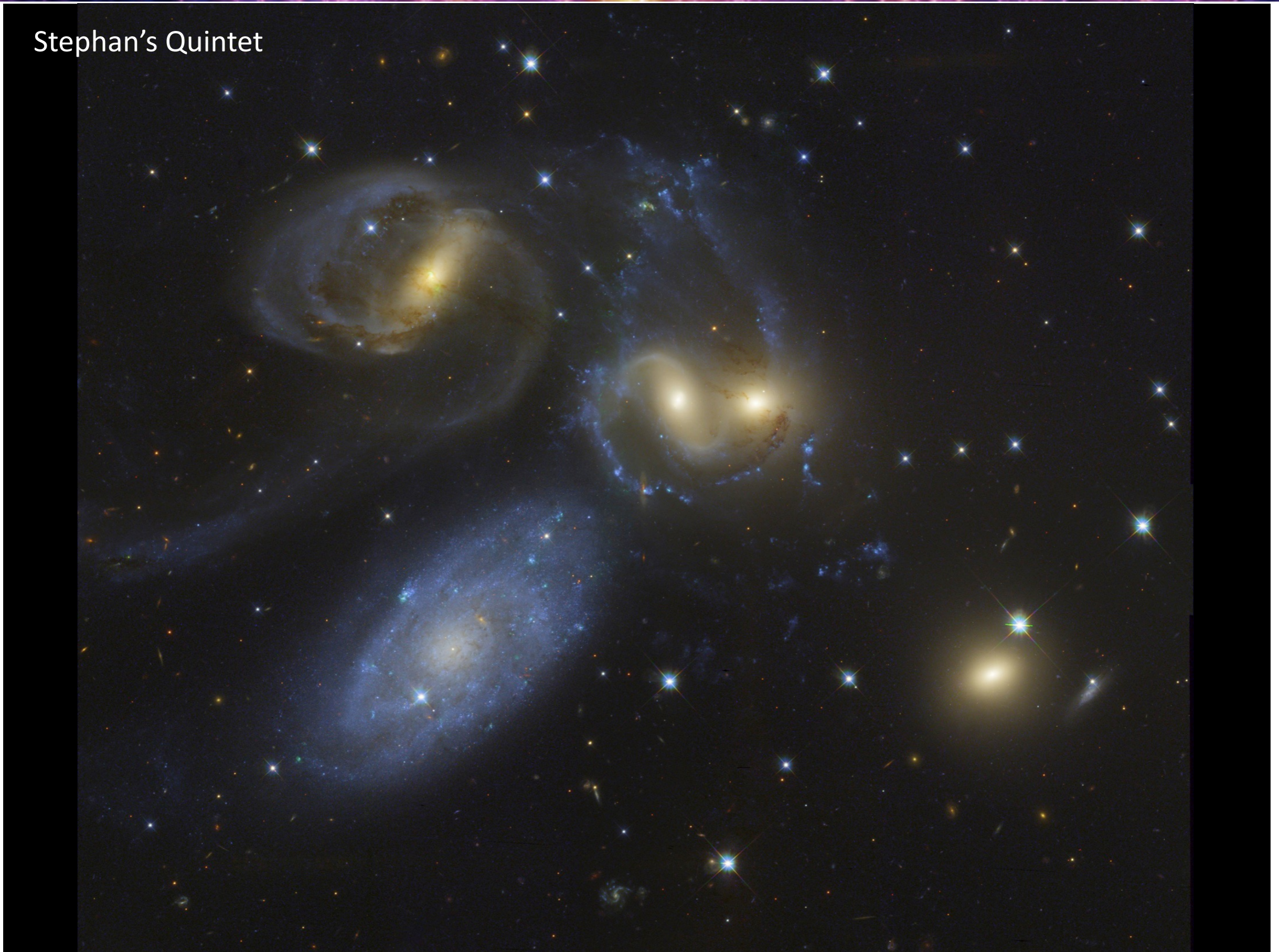


1 million ly



Galaxy environments — Groups

Stephan's Quintet



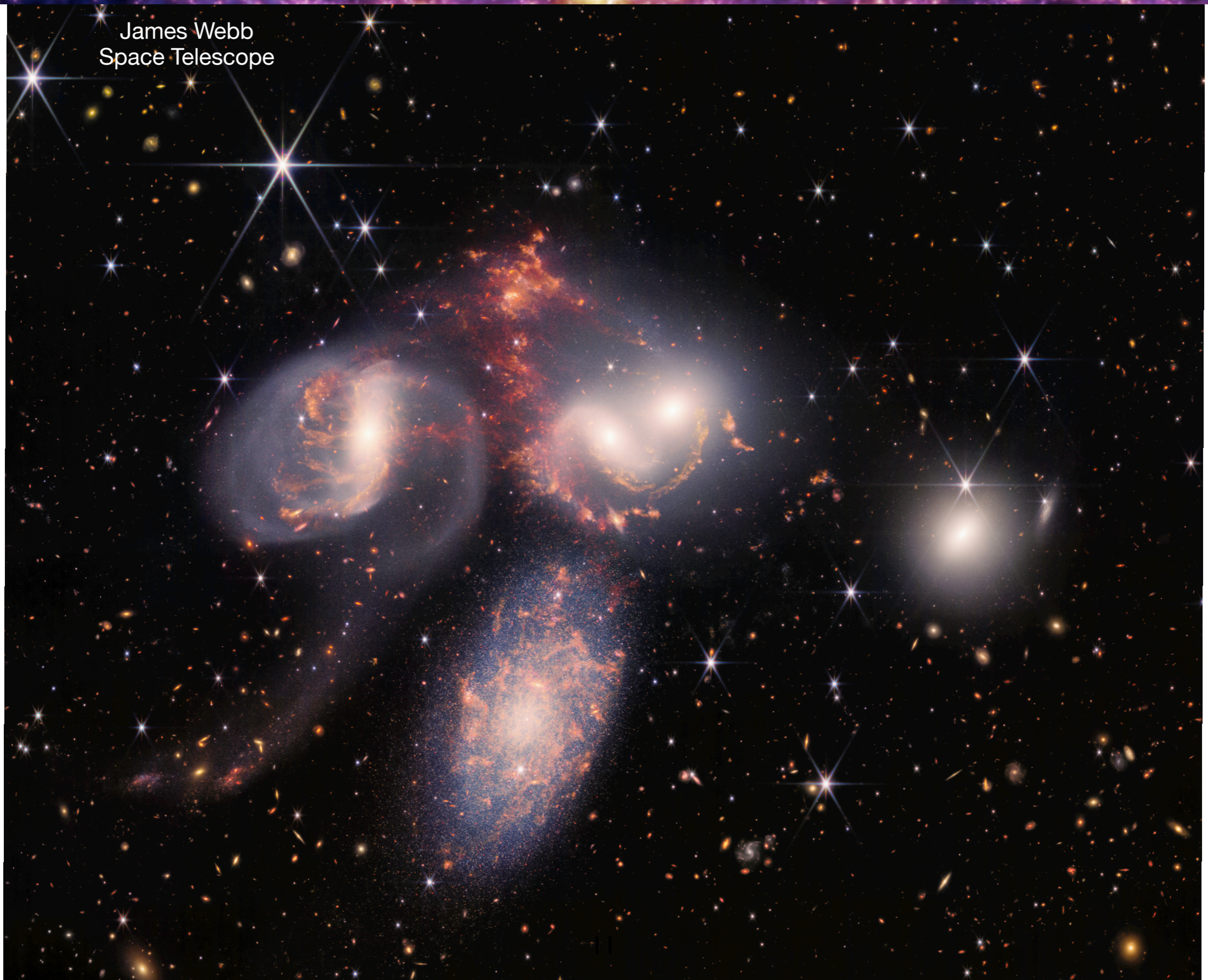
Galaxy environments — Groups

blue=visible starlight
red=infrared
green=H-alpha (ionized gas)



Galaxy environments — Groups

James Webb
Space Telescope



Galaxy environments — Groups

mergers

- galaxy groups are the ideal environment for mergers (why?)
- mergers can drive gas into galaxy nuclei, trigger starbursts, transform disks into spheroids, and feed nuclear black holes

Outline of Chapter 8

- Galaxies and their environment
 - Groups of galaxies
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Galaxy Clusters

- originally defined by number of members within a certain radius (e.g. 30 w/in $1.5 \ 1/h$ Mpc – Abell “richness” – massive clusters can contain hundreds of galaxies)
- velocity dispersions $> 700\text{-}1200$ km/s
- total masses $> 10^{14} M_{\text{sun}}$
- always contain hot gas -- X-ray temperatures $> \text{few } 10^7$ K

Galaxy environments — Clusters

Virgo cluster -- ~16 Mpc away

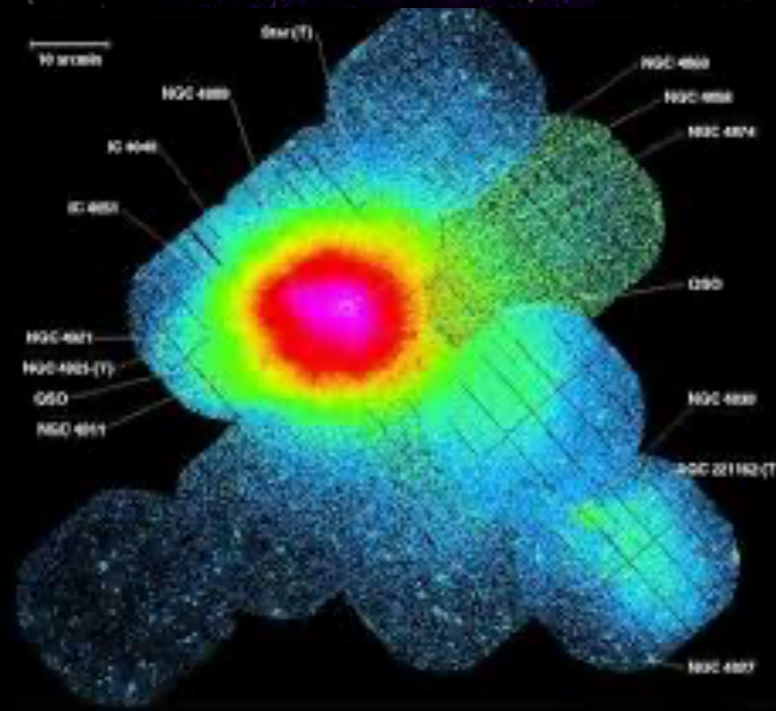
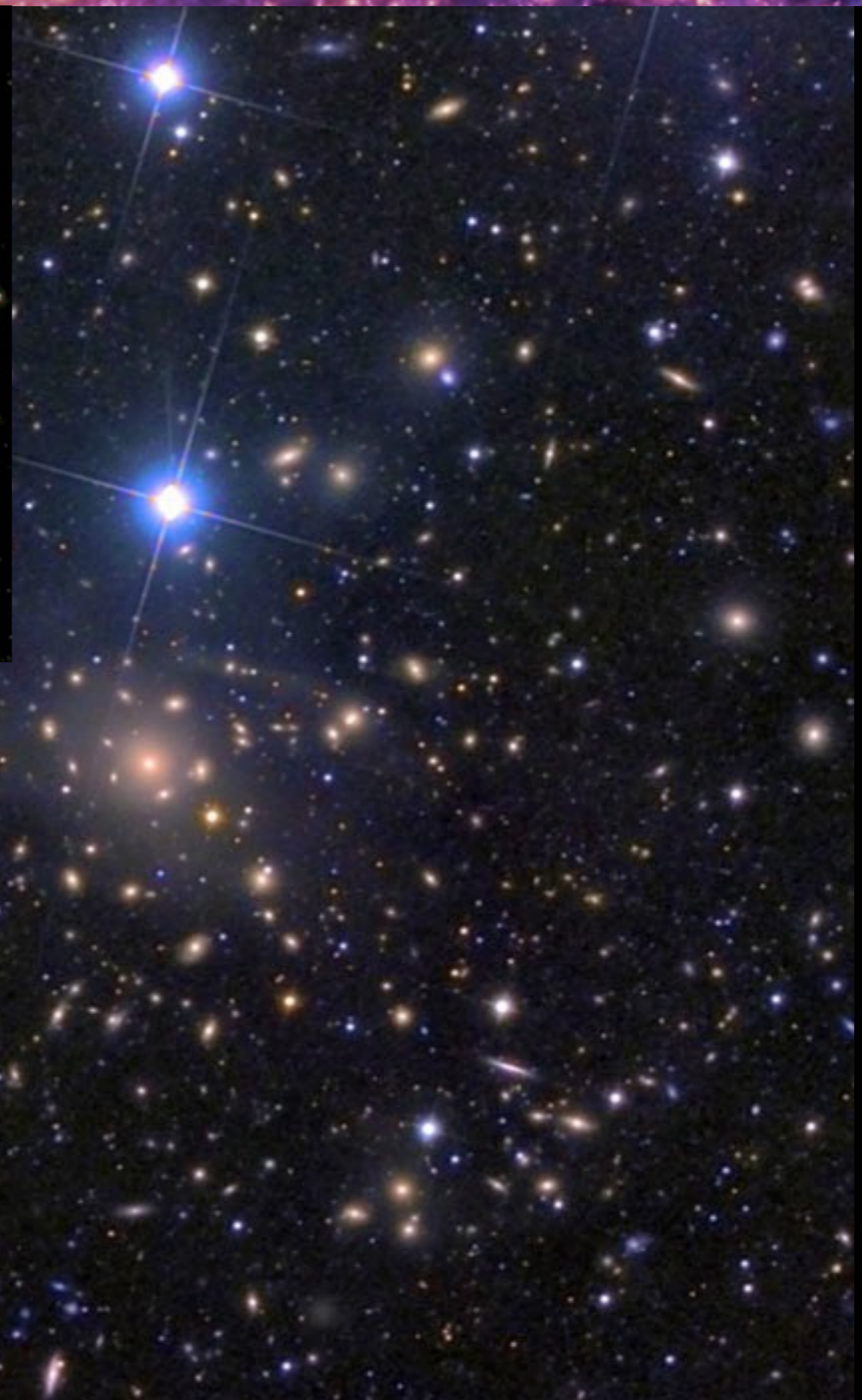
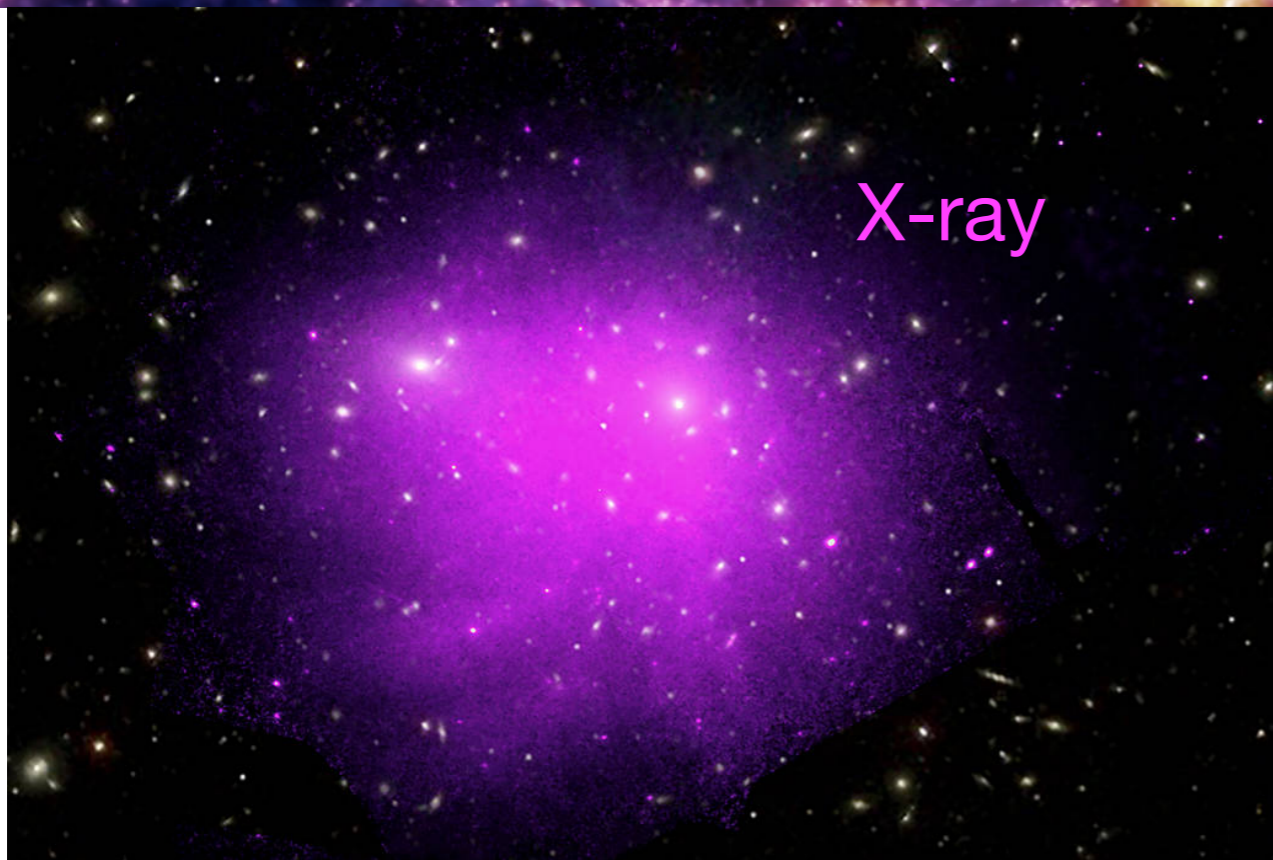


Galaxy environments — Clusters

Coma cluster



Galaxy environments — Clusters



hot gas in clusters

- the baryonic content of clusters is actually dominated by hot gas, not stars or cool gas ($M_{\text{hot}}/M_{\text{star}} \sim 1-10$, increasing with cluster mass)
- using the assumption of hydrostatic equilibrium, we can use the luminosity and temperature of the gas to estimate the cluster's total mass
- the hot gas fraction in the most massive clusters approaches the universal baryon fraction

Galaxy environments — Clusters

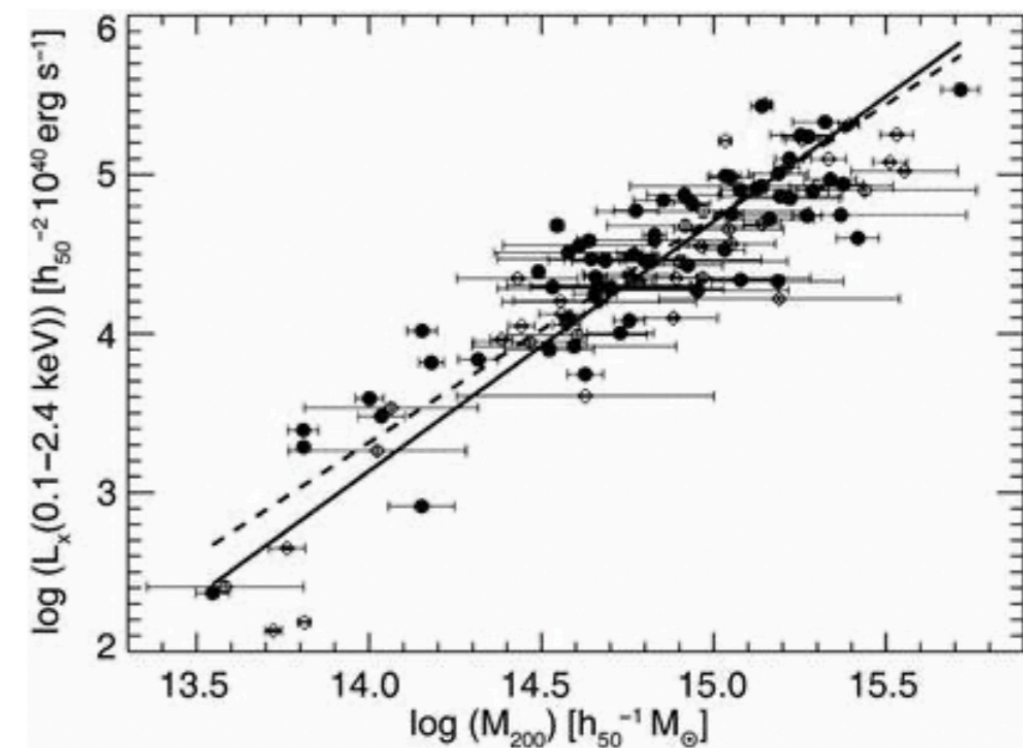
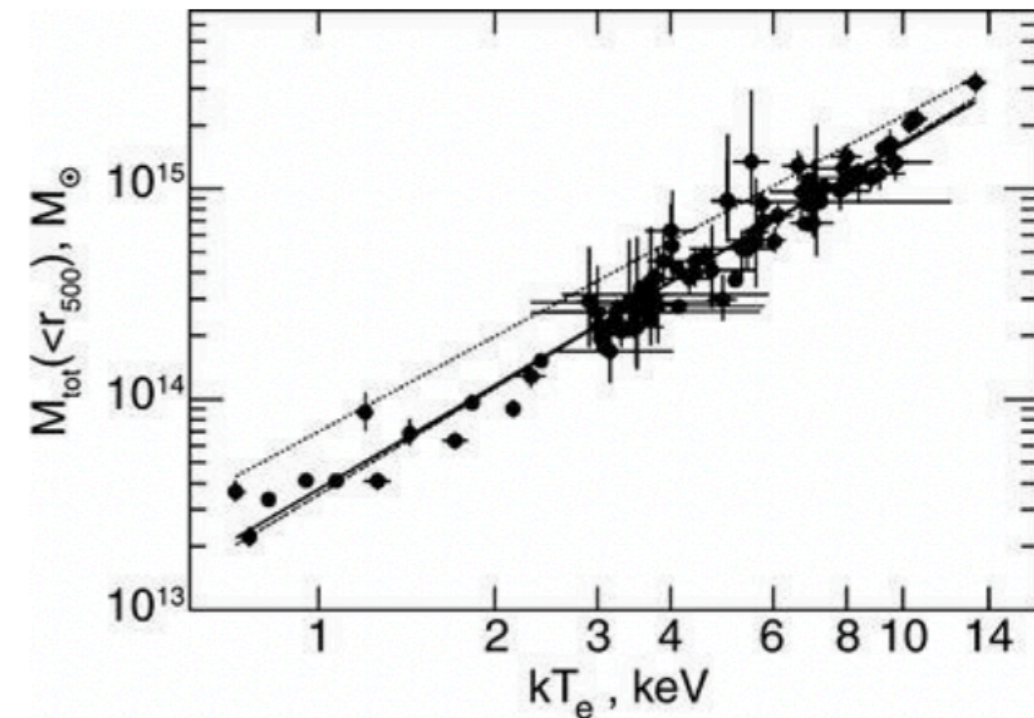
Scaling relations for clusters

- Mass-Temperature relation (X-ray T specified by the thermal energy per gas particle, which should be prop. to the binding energy for a cluster in virial equilibrium)

$$M_{500} = 3.57 \times 10^{13} M_{\odot} \left(\frac{k_B T}{1 \text{ keV}} \right)^{1.58}$$

- Mass-luminosity relation: X-ray luminosity is prop. to the gas density and volume, and thus, to (the gas fraction and) the total mass:

$$L_{X, < 2.4 \text{ keV}} \propto M_{tot}$$



Galaxy environments — Clusters

Evidence for Dark matter from Galaxy Clusters

- First indication for dark matter from observing clusters of galaxies
- 1933: F. Zwicky: hint for other form of matter when looking at the stability of Coma cluster using the virial theorem ($2K-U=0$).

$$M = \frac{r_G \langle v^2 \rangle}{G}$$

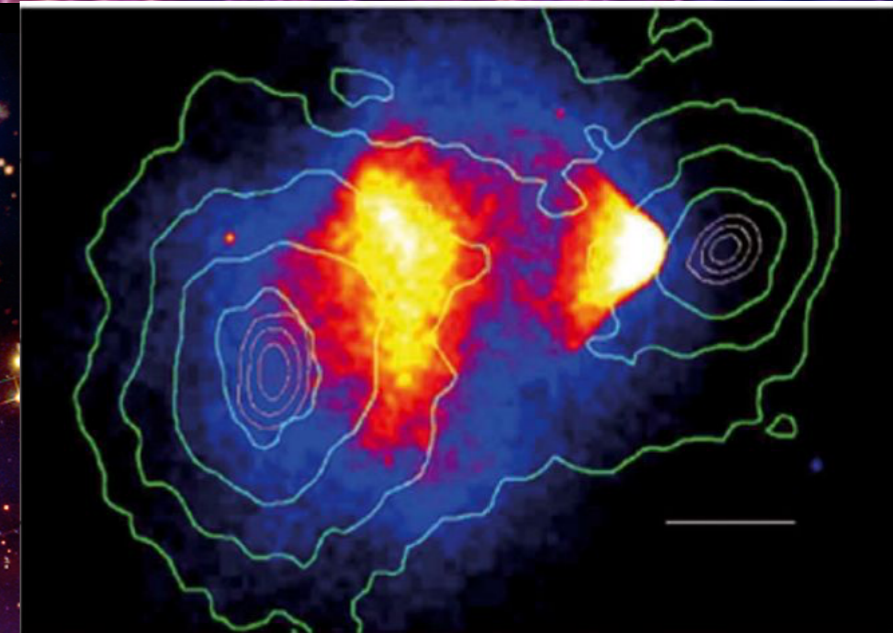
- Applying the virial theorem to the Coma cluster: galaxy movements cannot be explained by luminous matter, too fast movements, galaxies would fly apart → missing matter needed to explain gravity (up to 90% non-luminous matter)

Galaxy environments — Clusters

Bullet Cluster

X-ray illustrating hot gas

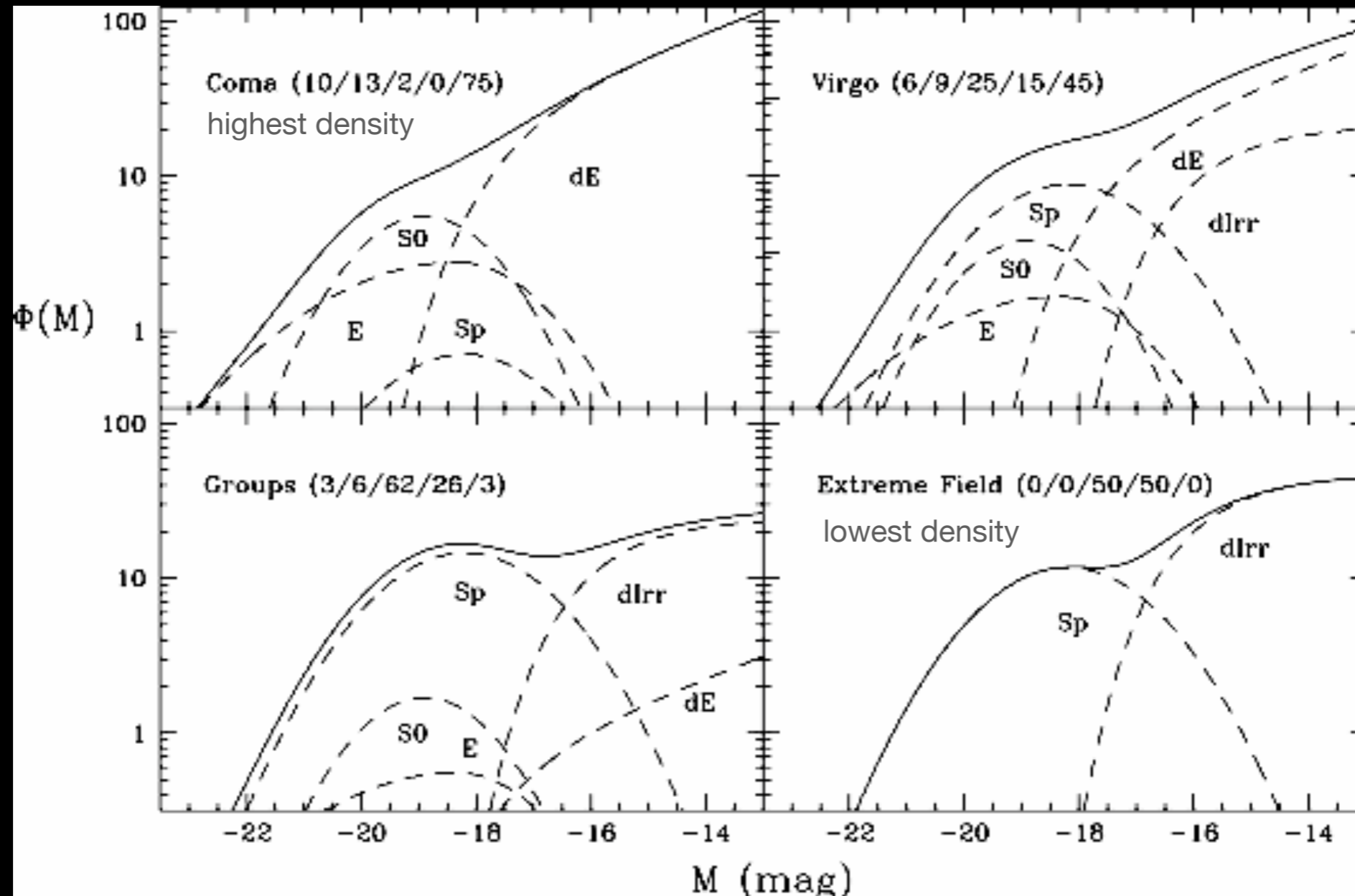
Total Matter density (dom. by DM) from
Gravitational lensing



1.5'

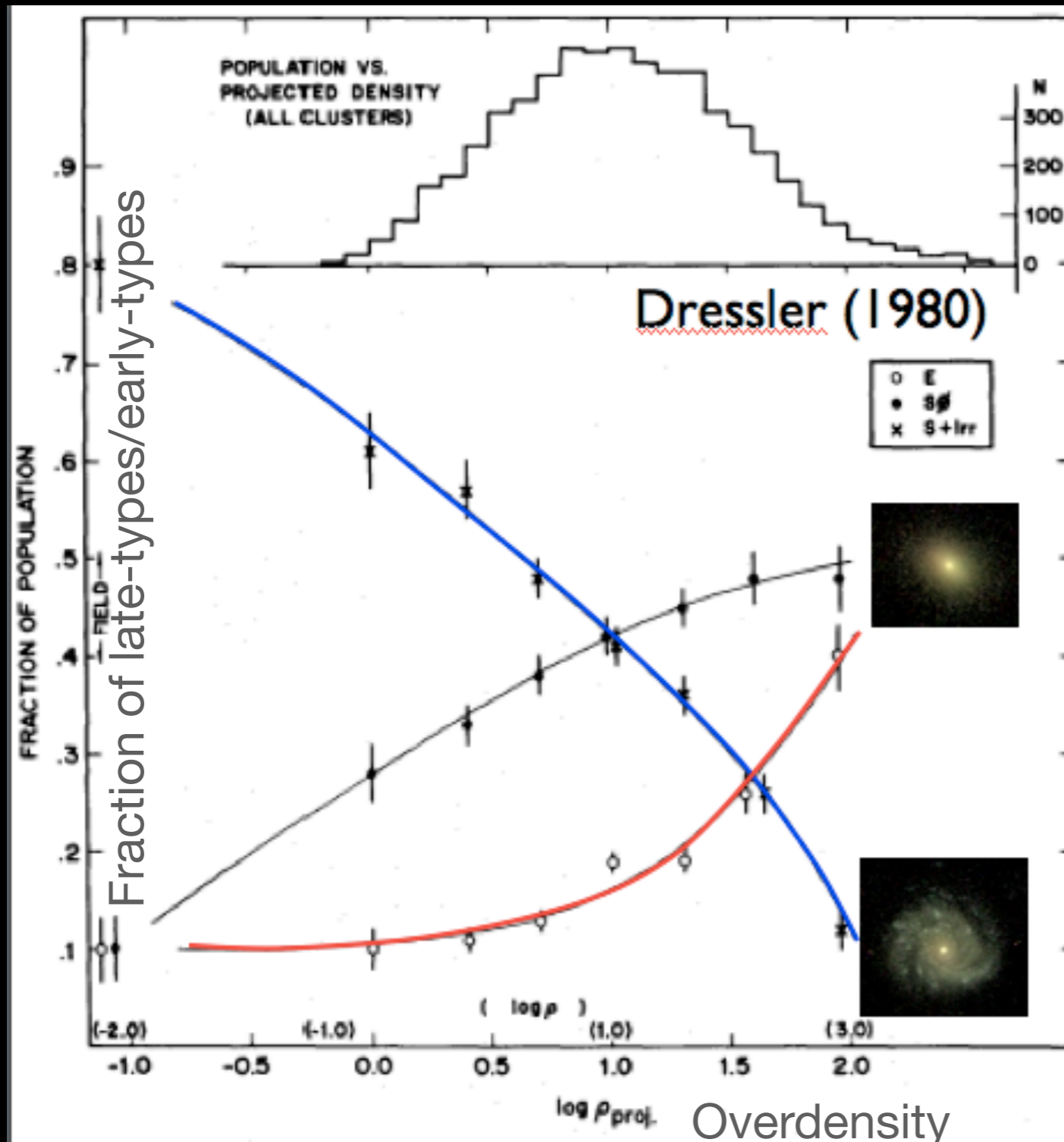
Galaxy environments — Clusters

How does the prevalence of different galaxy types (E, S0, Sp, dlrr and dE) change with density?



Galaxy environments — Clusters

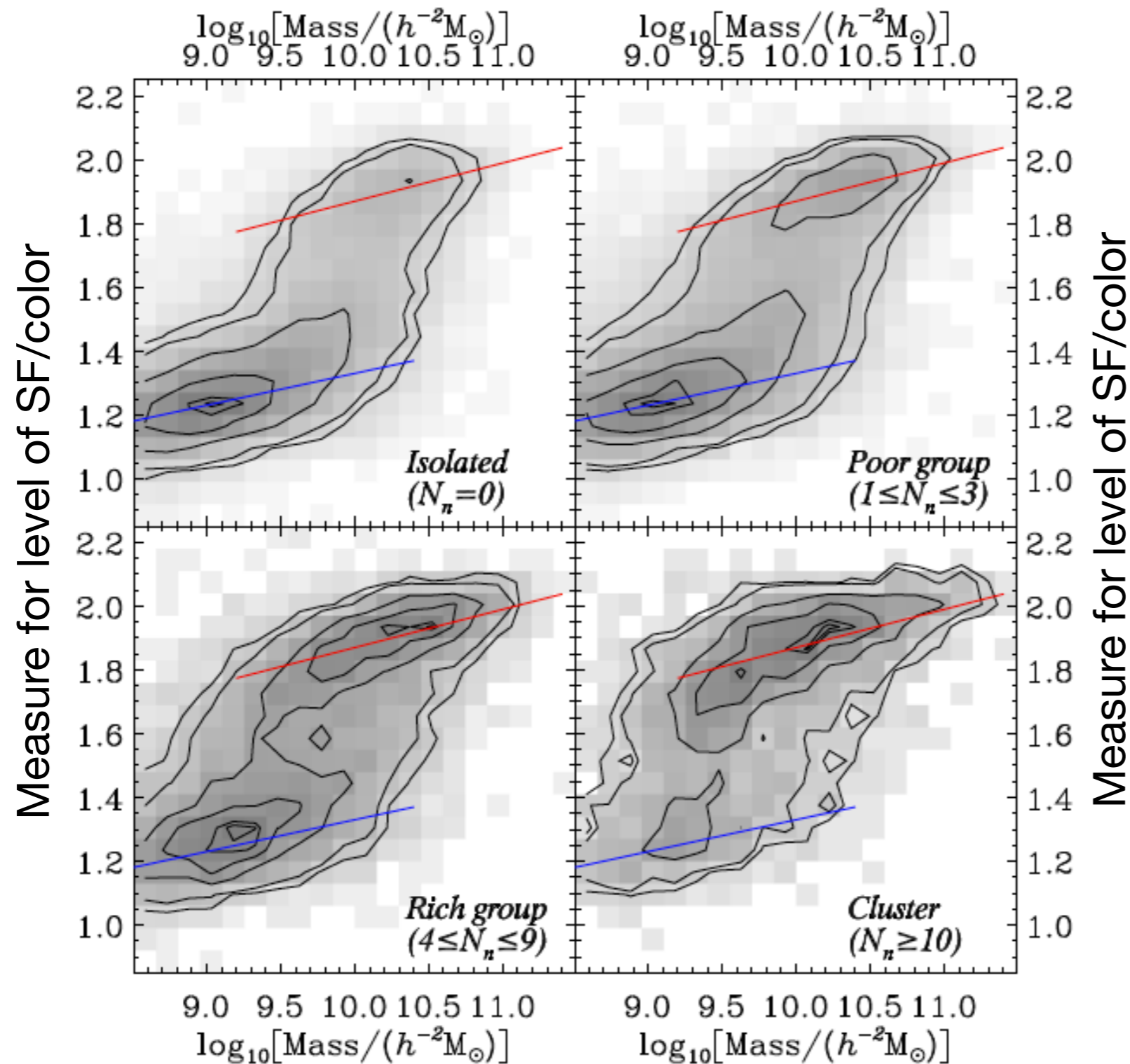
The “morphology-density” relation



as density increases, whether within a cluster or in different environments (field, group, cluster), the fraction of early type galaxies *increases* and the fraction of late type galaxies *decreases*

Processes ongoing which transform galaxies to be more elliptical/spheroid dominated at high densities

Galaxy environments — Clusters



similarly, the fraction of old, or red, or quiescent galaxies increases in denser environments

Blanton & Moustakas

What is the origin of these relations between galaxy properties and density?

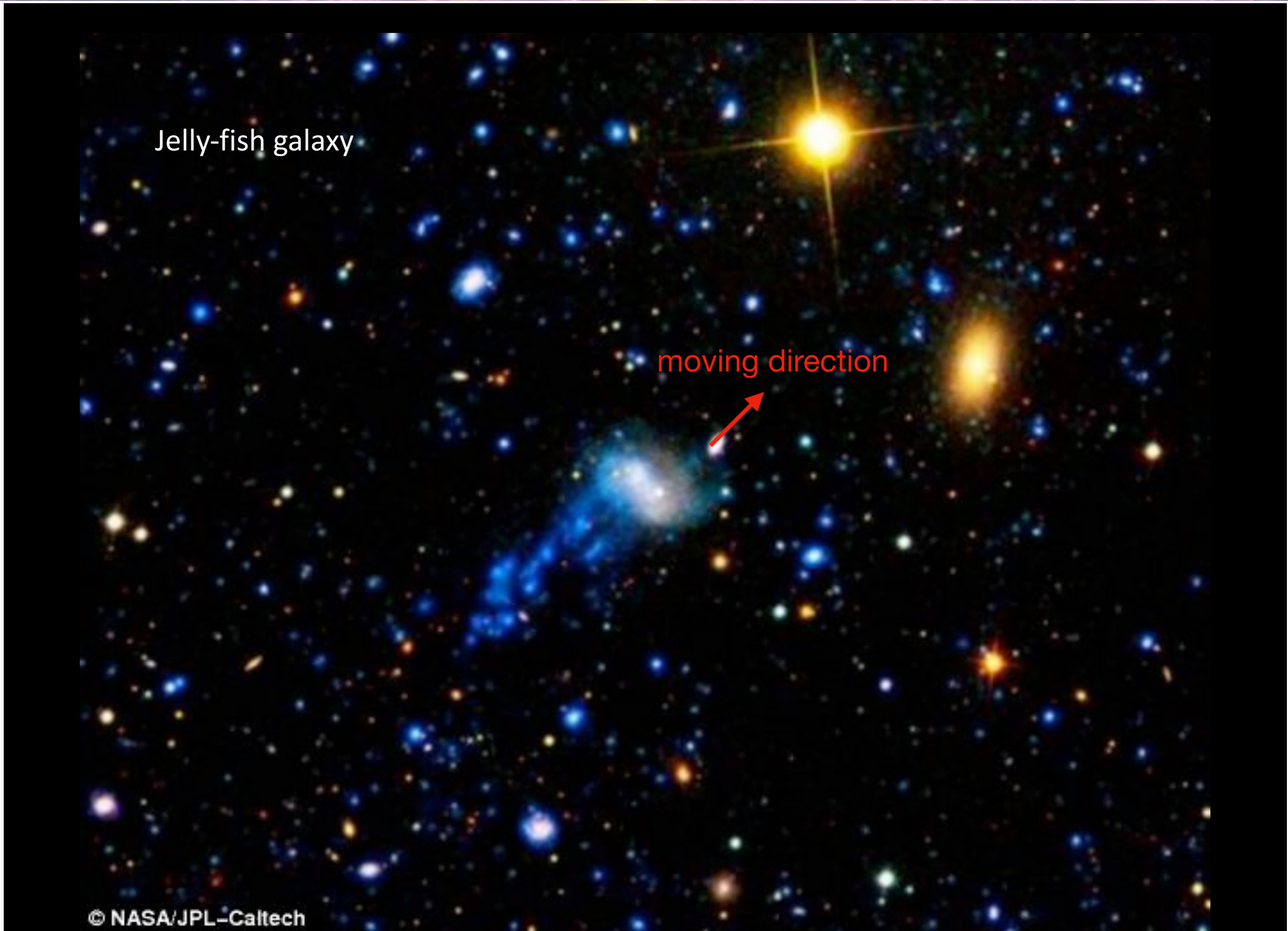
The violent world of clusters

- tidal and ram pressure stripping – cold gas stripped out by dark matter or hot gas in cluster
- galaxy harassment: morphological disturbance due to unbound interactions (fly-bys)
- strangulation: non-central galaxies deprived of new cold gas because they are not at the center of the potential well
- galactic cannibalism: satellite galaxies get ‘eaten up’ by the cD galaxy

Galaxy environments — Clusters

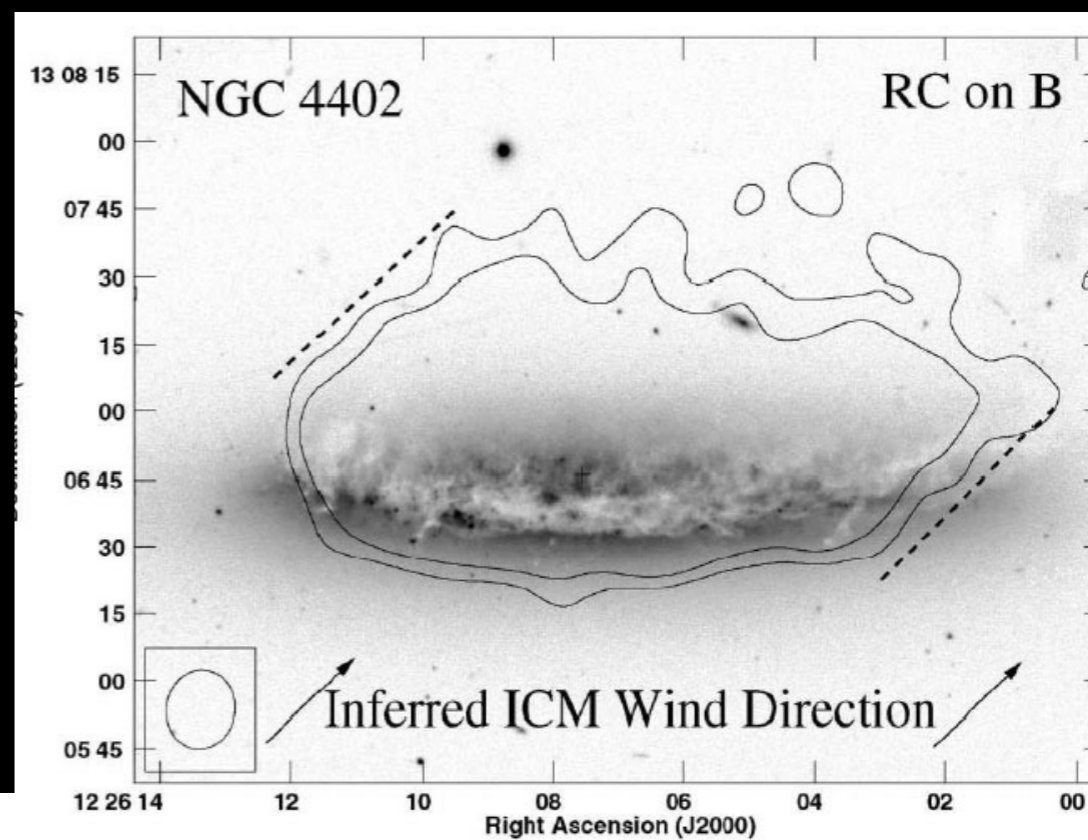
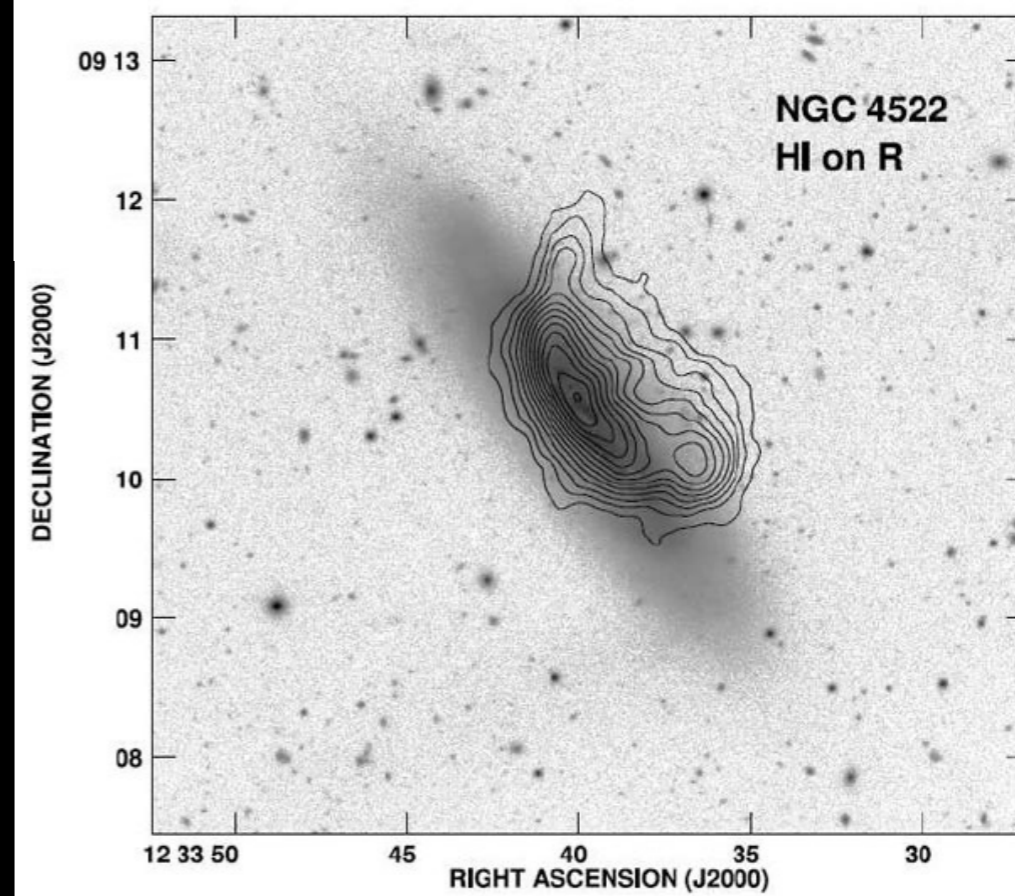
Jelly-fish galaxy

moving direction



Galaxy environments — Clusters

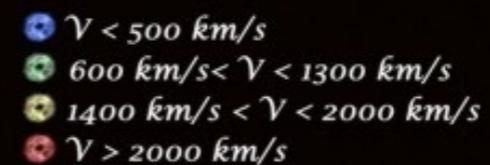
(tidal and ram pressure) stripping



Galaxy environments — Clusters

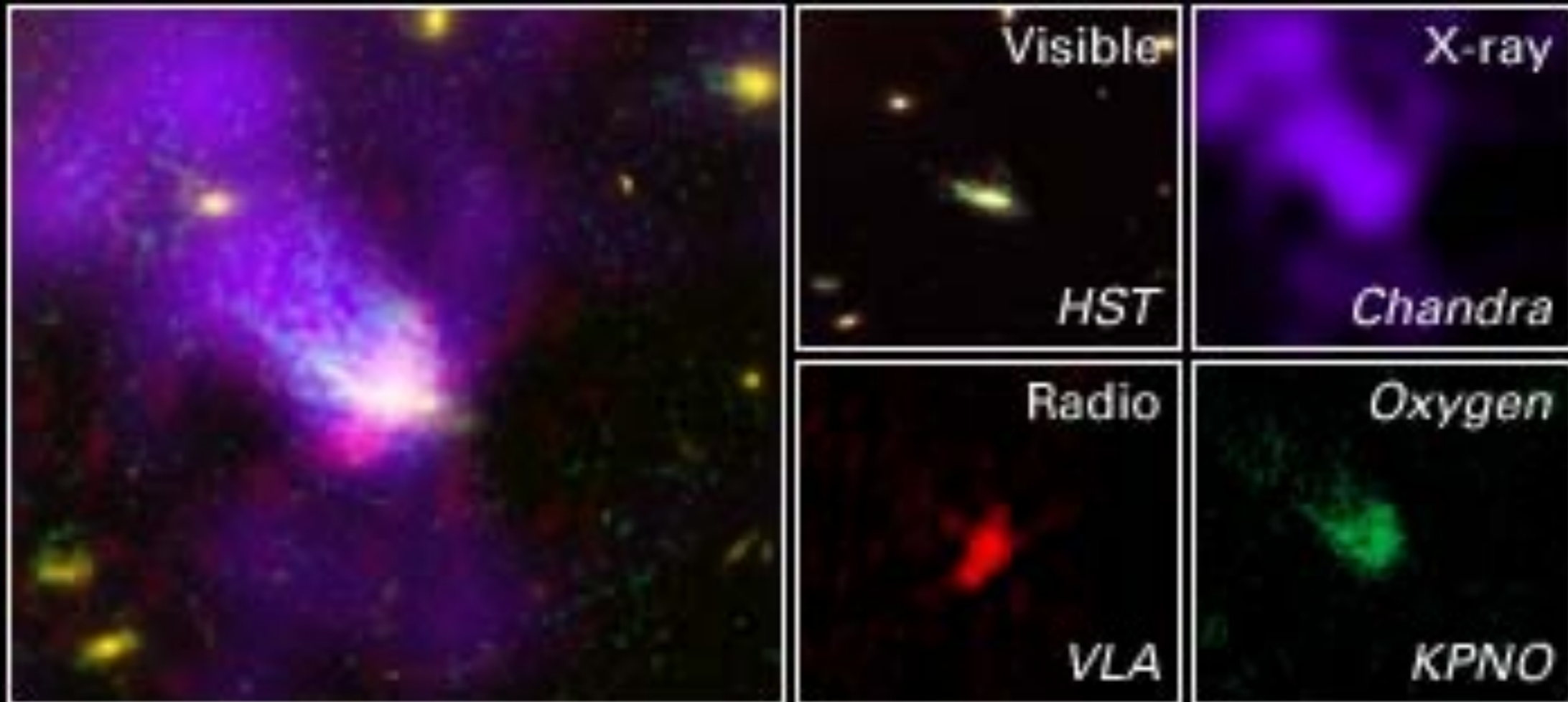
map of HI in the
Virgo Cluster

disks become more
and more 'HI deficient'
towards the centers
of clusters



Galaxy environments — Clusters

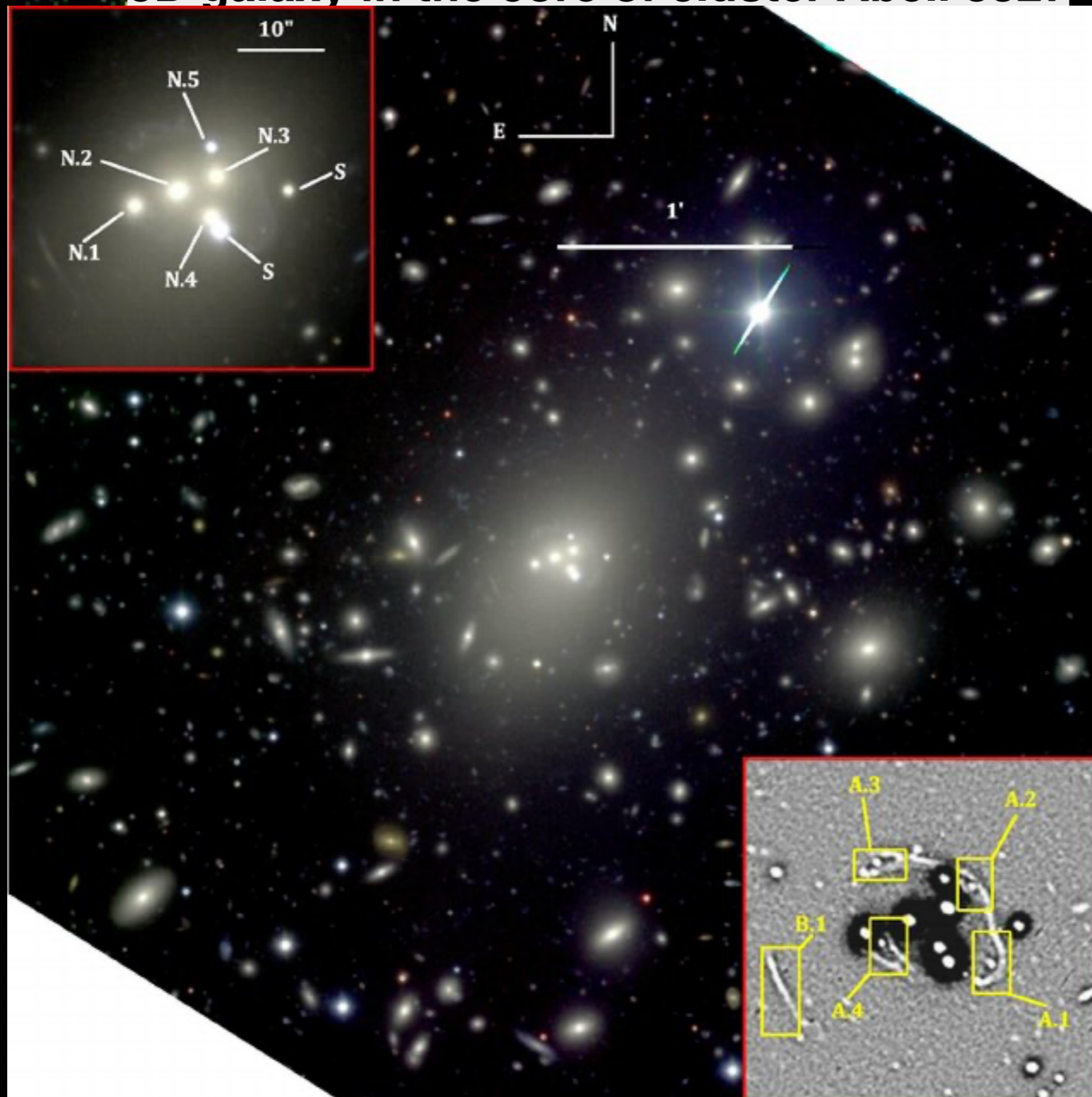
galaxy 'harassment'



Galaxy environments — Clusters

Galactic Cannibalism?

cD galaxy in the core of cluster Abell 3827



Galaxy environments — Clusters

How can environmental processes change galaxy properties?

- Ram-pressure stripping of gas and strangulation: deprive galaxy of (cold) gas \rightarrow shutting off SF \rightarrow quiescent galaxies
- Tidal/gravitational interactions and harassment: less-bound stars at large radii can be stripped + little SF in a disk due to gas stripping \rightarrow transition from late-type to early-type morphologies
- Mergers in the centres \rightarrow giant ellipticals/cDs/BCG

Galaxy environments — Summary

- Densest environments are groups and clusters of galaxies
- Groups: a few 10^{12} - a few $10^{13} M_{\text{sun}}$
- Clusters: $>10^{14} M_{\text{sun}}$, contain hot, X-ray luminous gas
- Scaling relations of galaxy clusters (e.g, T-M, L_x -M)
- Environmental dependencies of galaxies:
 - Morphology-density relation
 - Color/sSFR-density relation
- Galaxies in dense environments likely subject to
 - mergers/galactic cannibalism
 - ram-pressure/tidal stripping of gas
 - strangulation
 - harassment

Galaxy environments — Clusters

“Nature” vs. “Nurture”

- What causes the observed correlations in galaxy properties? Is it something in their “DNA” (Nature) or something about their environment (“Nurture”)?
- probably a bit of both...think of some examples of each.

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