Gas morphology and ram pressure stripping in nearby clusters

Possible Drivers for Environmental Evolution in Dense Environments

Gravitational

galaxy galaxy : slow encounters mergers - tidal structures
galaxy cluster : tidal stretching
galaxy many galaxies: harassment
cumulative effect of many fast encounters truncates or destroys small galaxies

Affects both gas and stars

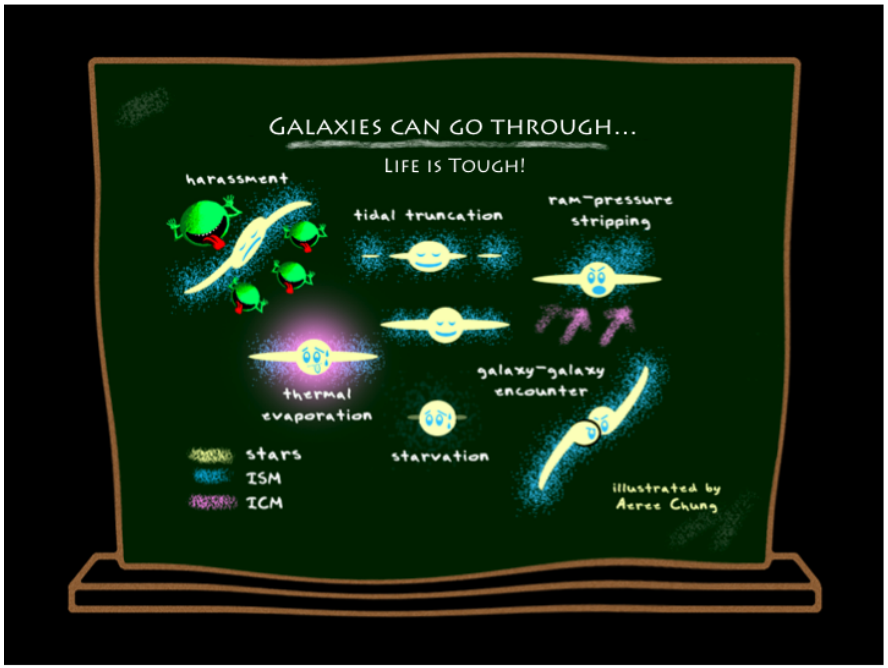
Gas dynamical effects

ram pressure stripping
turbulent viscous stripping
conduction

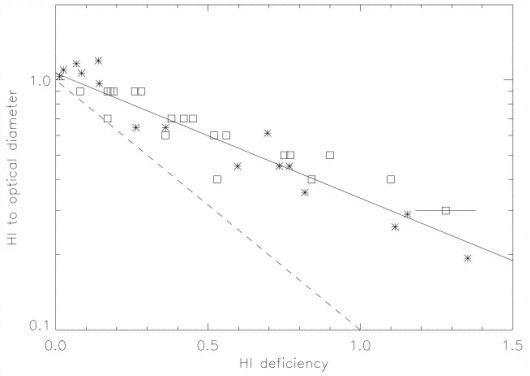
Affects only the gas

Starvation

removes left over gas reservoir that fuels star formation



Gunn and Gott (1972) back of the envelope… compare ram pressure ICM to restoring force in disk…predict stripping radius, beyond this radius gas will be removed

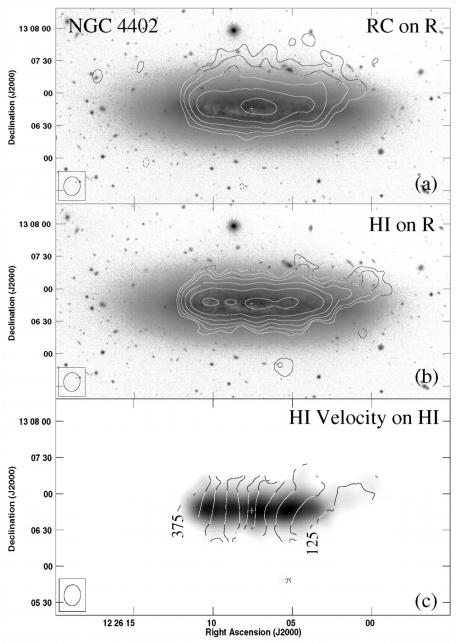


Here are the data

Normalized HI to optical diameter as function of HI deficiency. Squares observed values, stars model values.

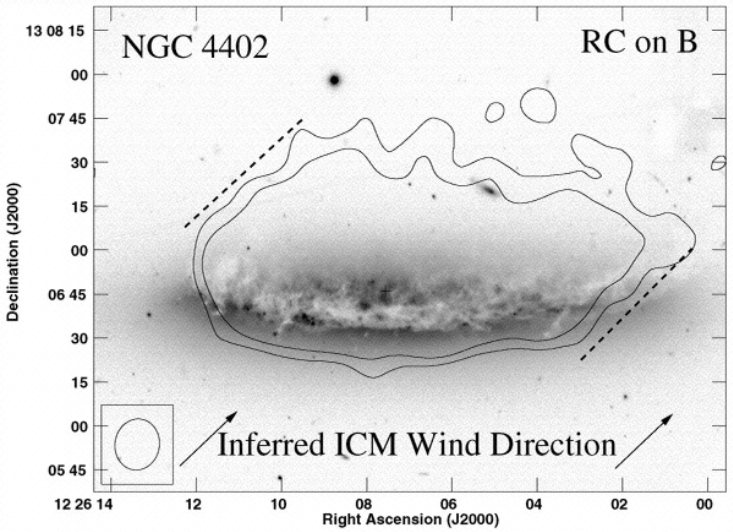
Solid line corresponds to case where HI surface density remains unchanged in stripping event (Vollmer 2001)

Confirms stripping radius

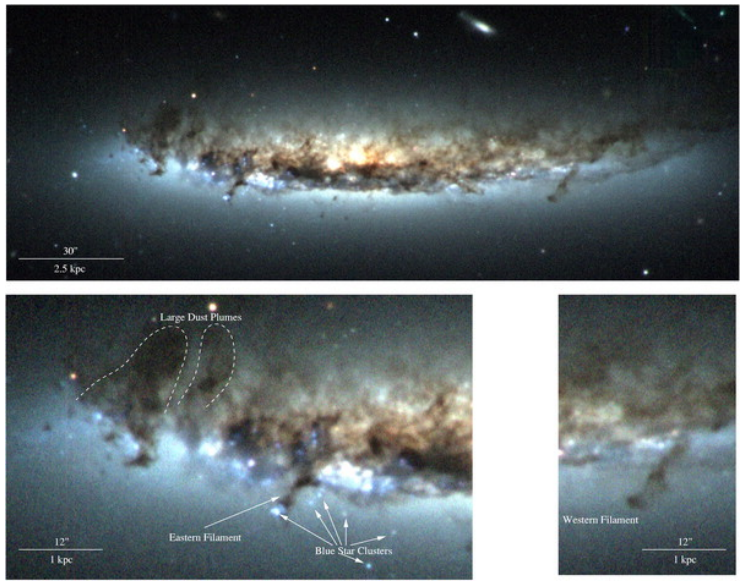


Crowl et al, 2005, AJ 130, 65

The morphology of ram pressure stripping



Outer two 1.4 GHz radio continuum contours on the WTTM *B image. The dashed lines indicate the "sharp ridges with well-determined position angles" discussed in the text. The inferred projected ICM wind direction (P.A. = -43), as calculated from the average of the position angles of the filaments and of the radio continuum ridges, is indicated with arrows at the bottom of the image.*



BVR color image (top) of NGC 4402, with detail images of the western filament (bottom right) and eastern filament and blue star clusters (bottom left).

VIVA

VLA Imaging of Virgo Galaxies in Atomic Gas

Aeree Chung, Hugh Crowl, Anne Abramson

Kenney, van Gorkom, Vollmer, Schiminovich

Select galaxies over wide range of local densities

Select galaxies with wide range of star formation properties

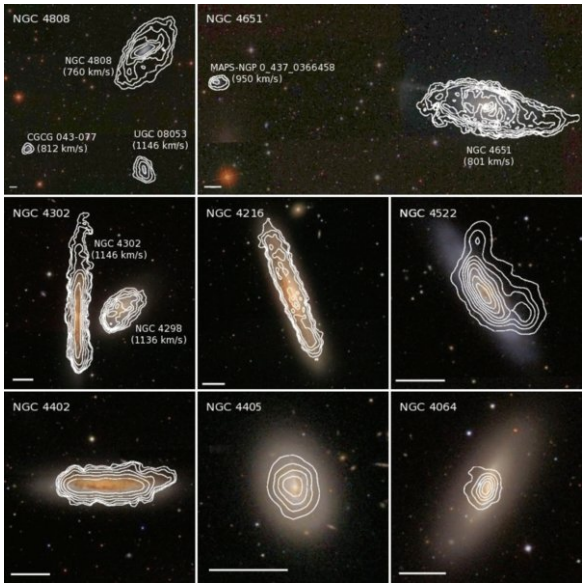
Identify galaxies undergoing trauma

Make sophisticated guess as to what is happening

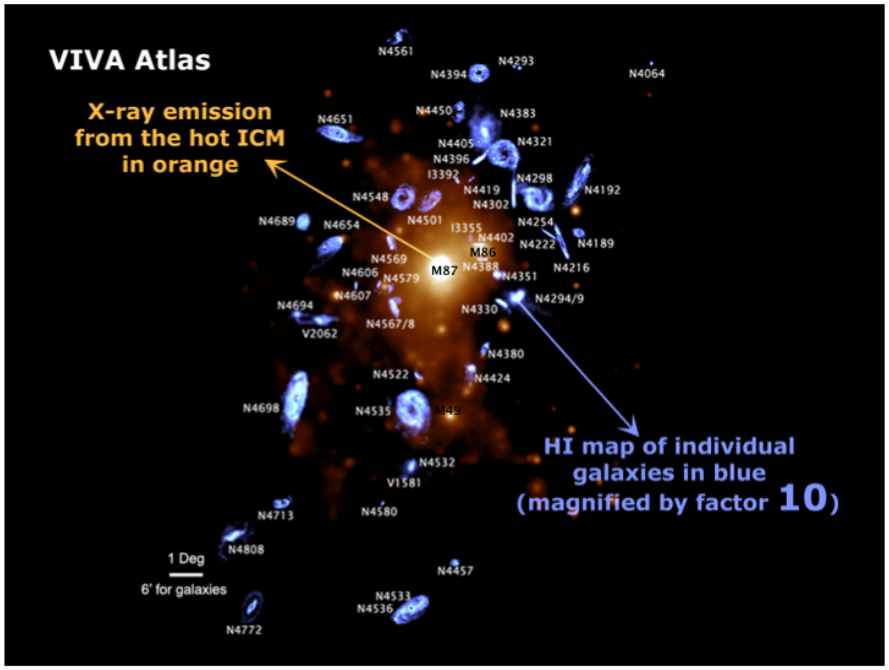
Use simulation to make a more sophisticated guess

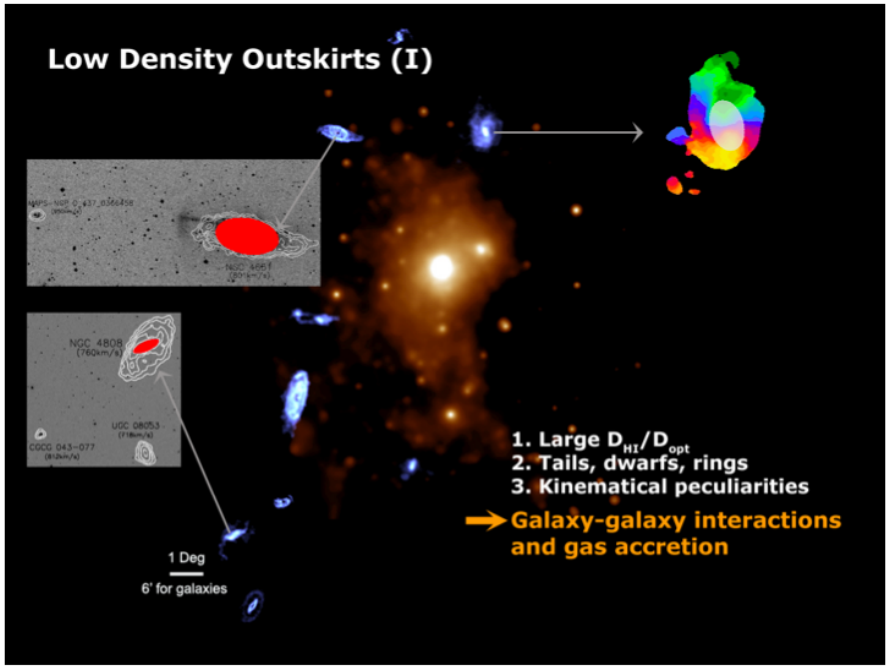
Compare timescales from stellar population synthesis with timescales from simulation

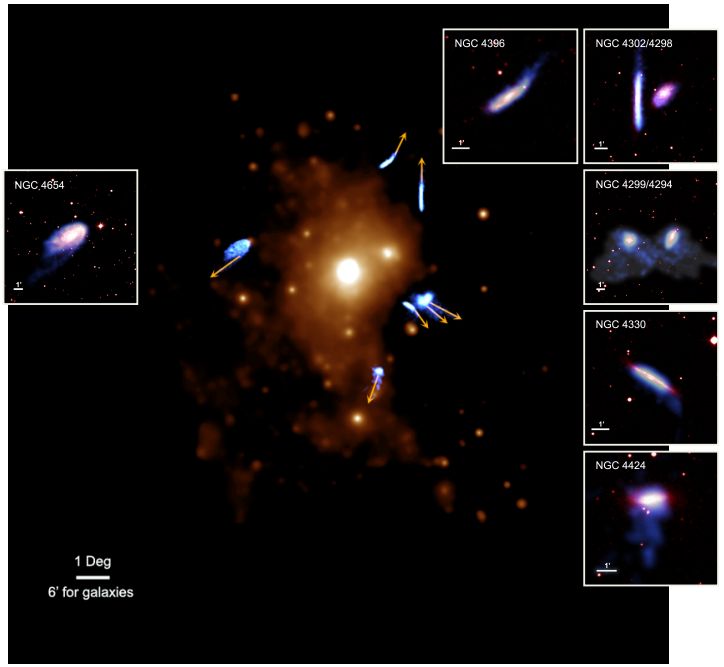
Chung et al 2007, 2009, Crowl et al 2005, Crowl and Kenney 2006, 2008, Abramson et al 2011

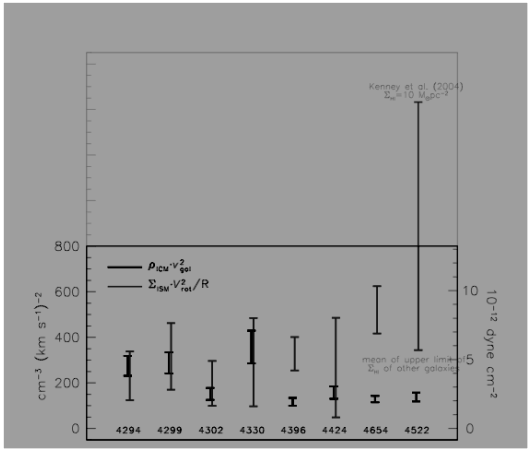


Chung et al, 2009









Can these tails be formed by ram pressure stripping?

Chung et al 2007

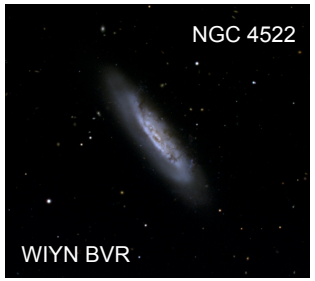
Five galaxy tails could have been formed by ram pressure

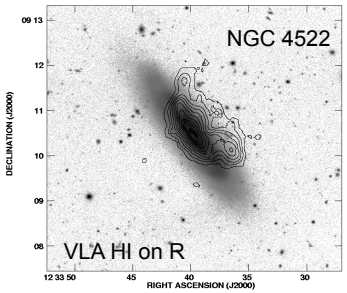
N4654 probably combination of gravitational and rp

N4396 possibly also, or viscous stripping

HI stripped from NGC 4522

Kenney, van Gorkom & Vollmer 2004





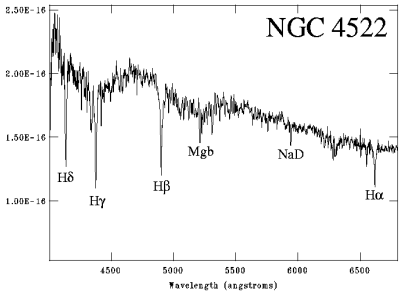
0.5L* galaxy with normal stellar disk

Has only 25% of normal HI (HI def =0.6)

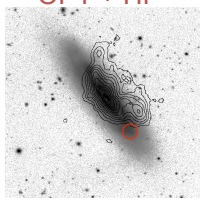
HI truncated in disk at $0.3R_{25}$

extraplanar HI (40% of total) on only one side of disk

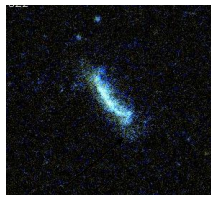
Young Stellar Population in Stripped Outer Disk of NGC 4522



OPT + HI



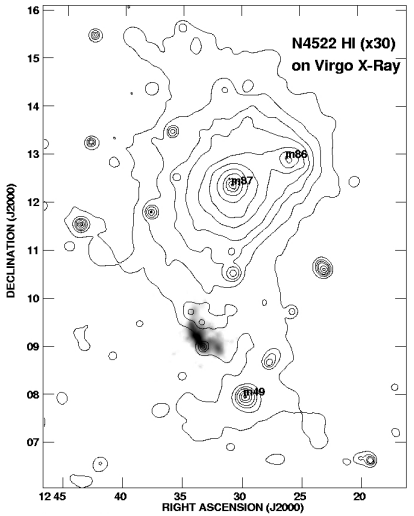
GALEX FUV+NUV



Strong Balmer lines and bright FUV emission in stripped outer disk indicate star formation stopped only ~100 Myr ago

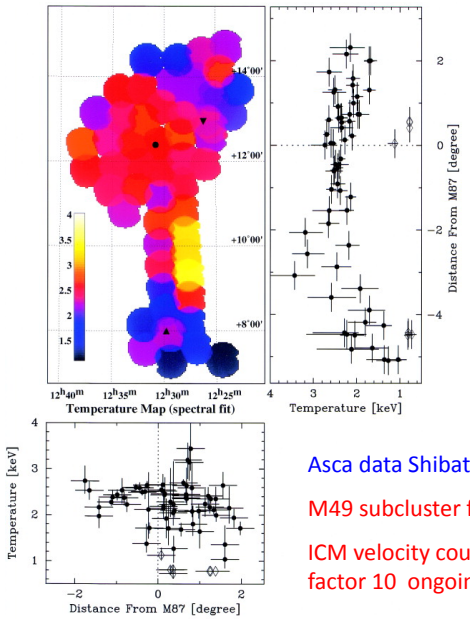
--> disk was stripped recently

Crowl & Kenney 2006



NGC 4522 is stripped locally and not in core

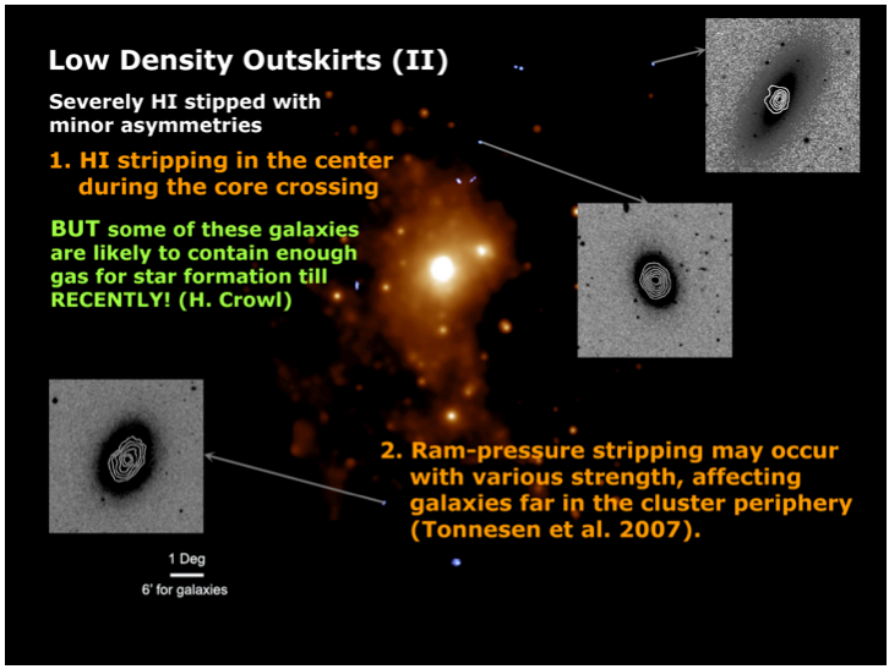
- NGC 4522 cannot travel far in 100 Myr, so must be stripped locally & not in cluster core
- NGC 4522 is located 3.5° = 0.8 Mpc from M87
- Time to reach core ~700 Myr

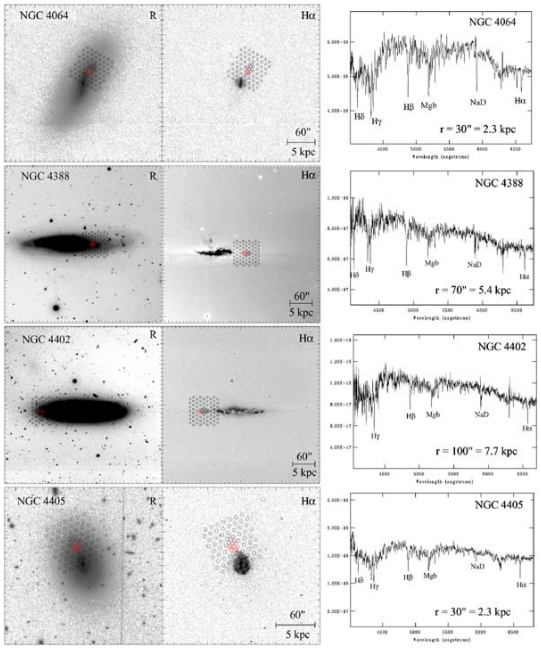


Asca data Shibata et al 2001

M49 subcluster falling in 1300km/s

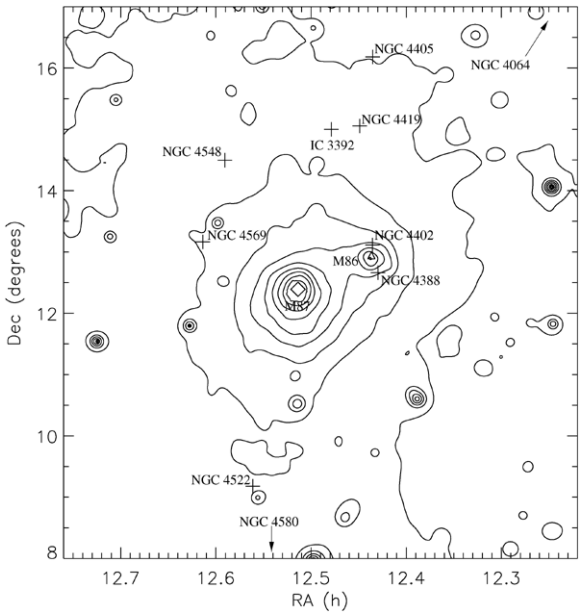
ICM velocity could increase ram pressure by factor 10 ongoing stripping



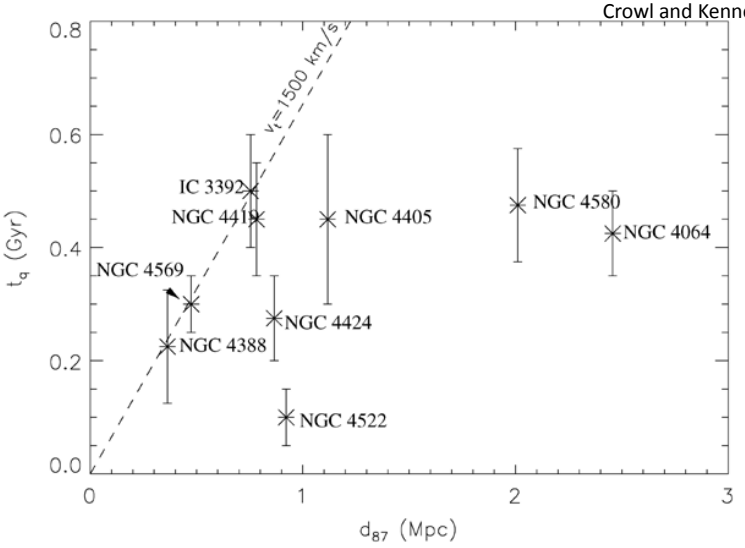


Crowl and Kenney 2008

- SparsePak positions on *R-band image (left) and Hα image (center). The composite spectrum from several summed fibers (indicated by the red circles on the images) is also shown (right). The radius given for each composite spectrum is the distance from the galaxy center to the center of the composite spectrum region. Shown here are images and spectra for NGC 4064, NGC 4388, NGC 4402, and NGC 4405.*

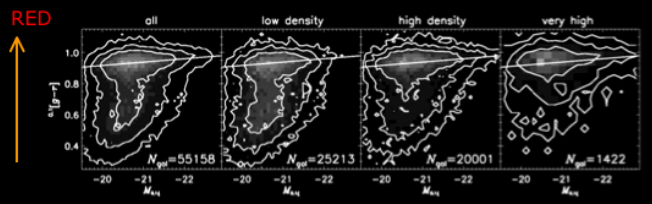


Crowl and Kenney 2008



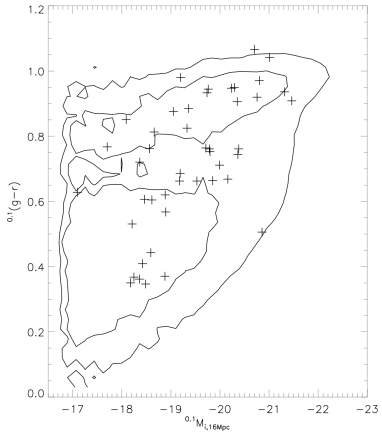
Quenching time for the sample of stripped spirals against projected distance from the central elliptical galaxy M87. Also shown (as a dashed line) is the position a galaxy would have if its star formation were halted in the core and it had been traveling 1500 km s^{-1} in the plane of the sky away from M87

ISM Stripping & Color Evolution



- ✓ Higher fraction of red galaxies in high density regions (Hogg et al. 2004): AGN? Mergers? ISM stripping?
- ✓ The VIVA sample is a good sample to inspect the impact of gas stripping on the color evolution of galaxies in clusters
- ✓ Any correlation between the HI properties and the color?

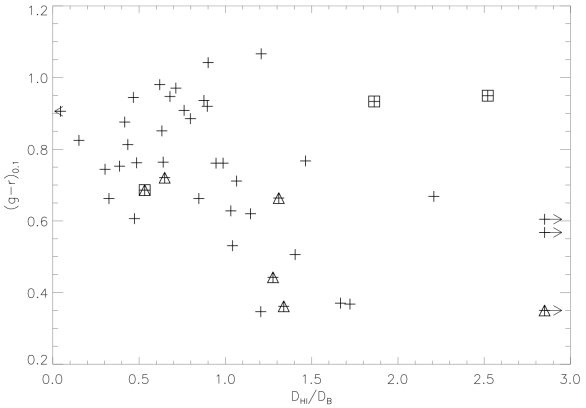
Crowl, Chung et al 2011, submitted to AJ



Crosses VIVA galaxies contours SDSS

Galaxies in blue cloud have D(HI)/D_{opt} > 1

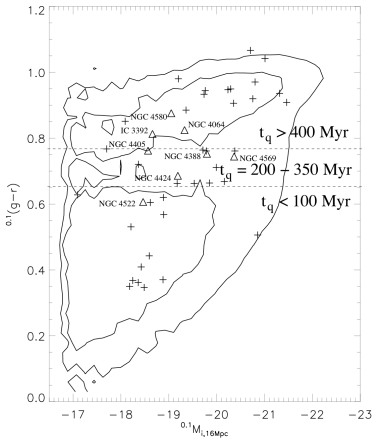
Galaxies on red sequence have mostly D(HI)/D_{opt} <1

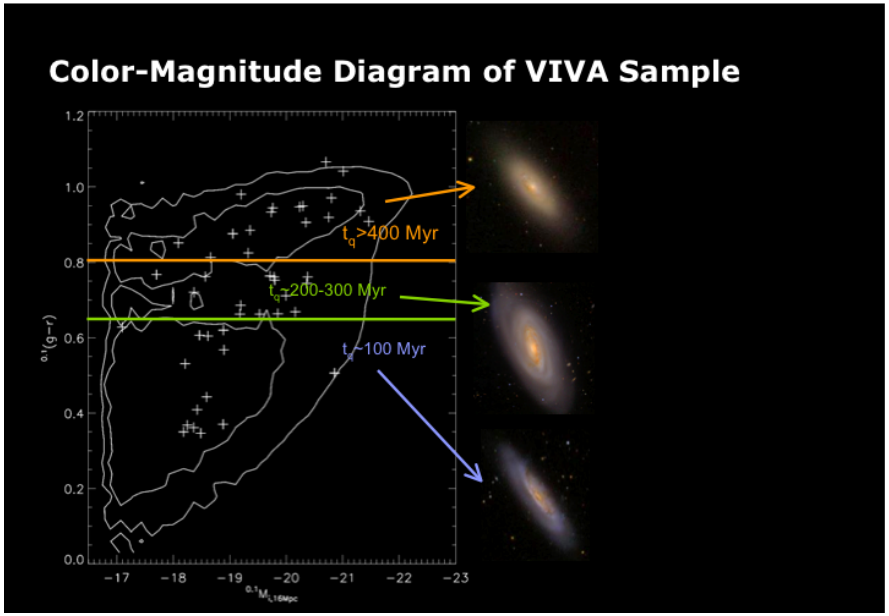


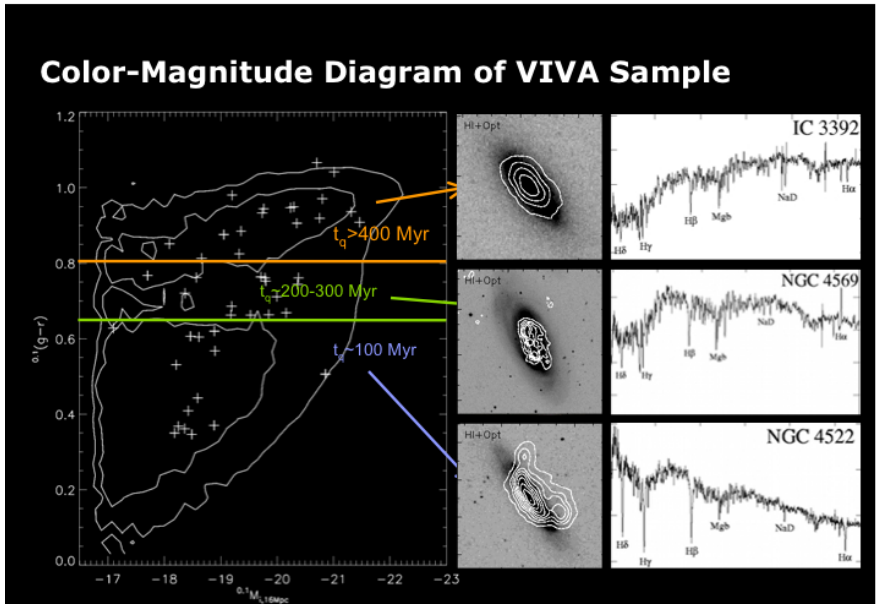
Triangles HI tails at about the virial radius of Virgo; squares merger remnants

For ram pressure stripped galaxies we can derive the timescale to cross the green valley

using the spectroscopically derived SF history Crowl and Kenney (2008)







Contours 140000 SDSS galaxies (Blanton et al 2003); + VIVA galaxies (Crowl et al 2011, submitted to AJ)

Conclusions from HI imaging of selected galaxies

In center we see very small HI disks.. Almost certainly due to ram pressure stripping

The stripping is important for the color evolution of the galaxies.

H alpha imaging (Koopmann Kenney 1998, 2004) shows that Virgo galaxies have reduced star formation rates compared to the field. This is primarily caused by truncation of starforming disks. A strong correlation is found between HI deficiency and normalized H alpha flux

Global colors are related to relative size of HI disks. It takes a few 100 Myr to change from blue to red after stripping to within disk

We see for the first time galaxies being affected at intermediate distances. Galaxies falling in radially are being affected by ram pressure and/or gravitational interactions.. preprocessing

Some galaxies at large distances being affected by strong rampressure.

Evidence for a dynamic ICM

What happens to ICM during cluster assembly

Movies by Greg Bryan (http://www.astro.columbia.edu/~gbryan/movies)

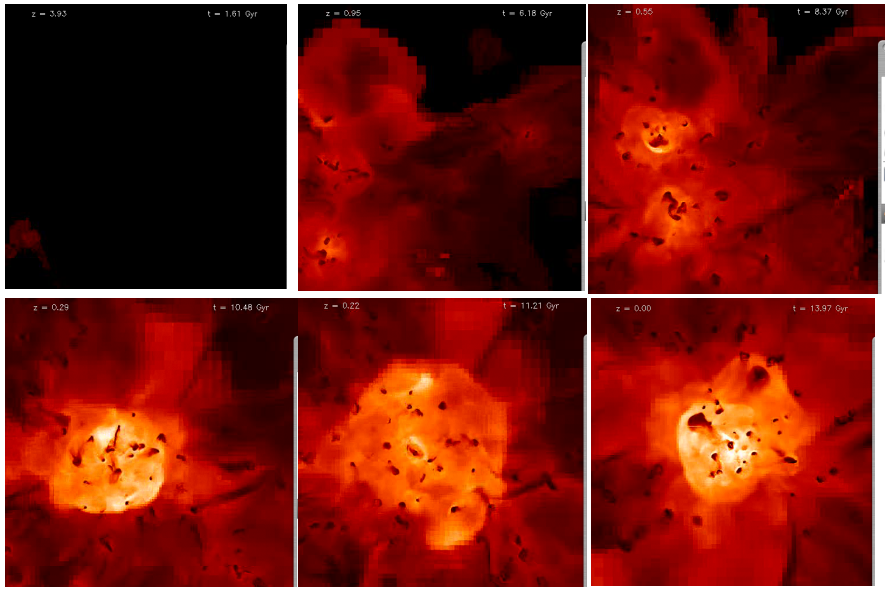
using a hybrid adaptive mesh refinement algorith

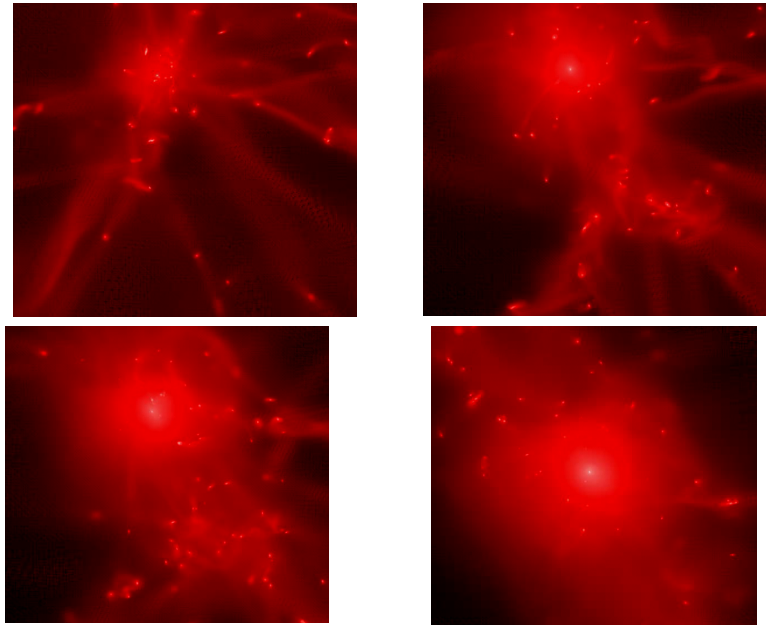
gaseous component, starformation, dark matter and stars

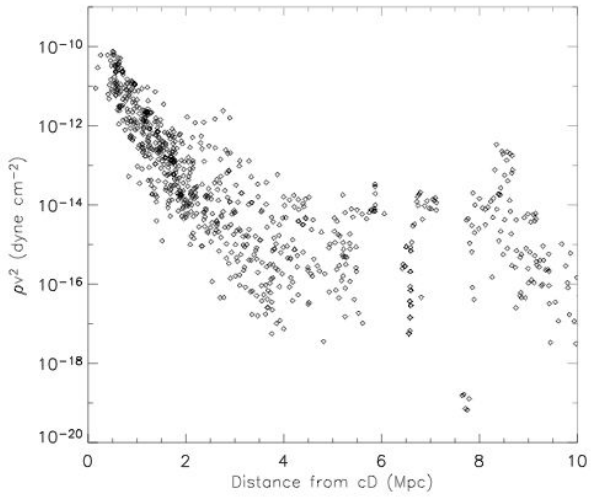
(ENZO)

1. Gas temperature: cosmological simulation of cluster assembly
2. High resolution gas density: evolution of 1 cluster

Analysis by Stephanie Tonnesen



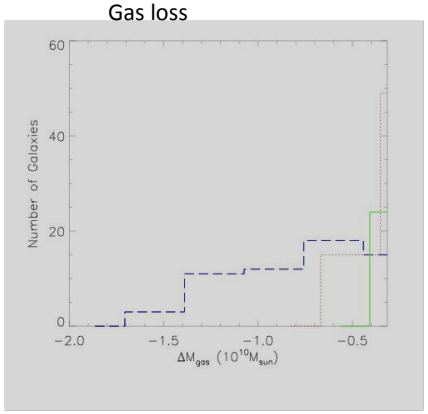




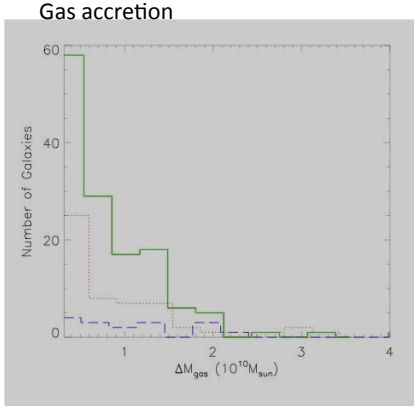
Ram pressure as function of distance from center

Tonnesen et al 2007

Gas loss



Gas accretion



0-1 Mpc 1-2.4 Mpc 2.4 - 5 Mpc

Changes in cool gas mass for the galaxies that have no changes in stellar mass.

Conclusions from simulation

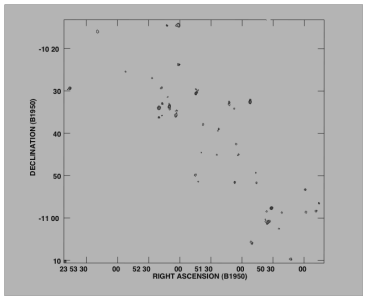
Tonnesen et al, 2007, ApJ 671, 1434

Ram pressure has large range of values at intermediate distances, some galaxies get stripped without ever going through core.. Slow process

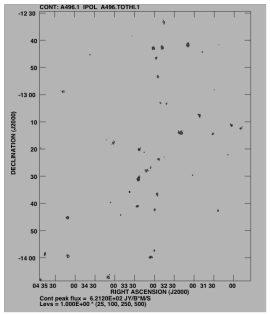
What do we see in other clusters?
Volume limited HI imaging

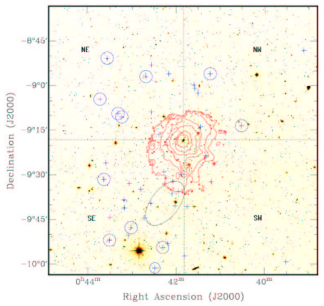
A2670

Total HI



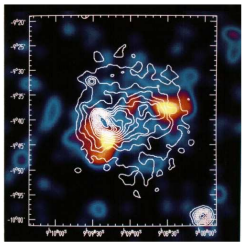
A496





A85

X-ray +HI



A754

X-ray

Detection rates in volume limited surveys

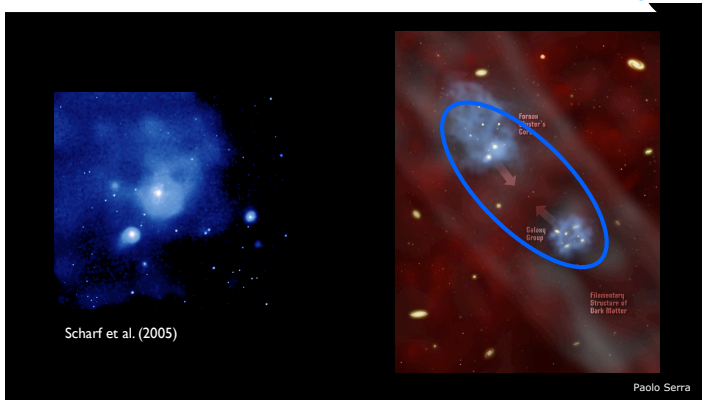
Hydra	50 galaxies	pre merger
A2670	50 galaxies	pre merger
A496	25 galaxies	beginning merger
A85	10 galaxies	ongoing merger
A 754	1 galaxy	just past merger

Detection rate depends on dynamical state of cluster

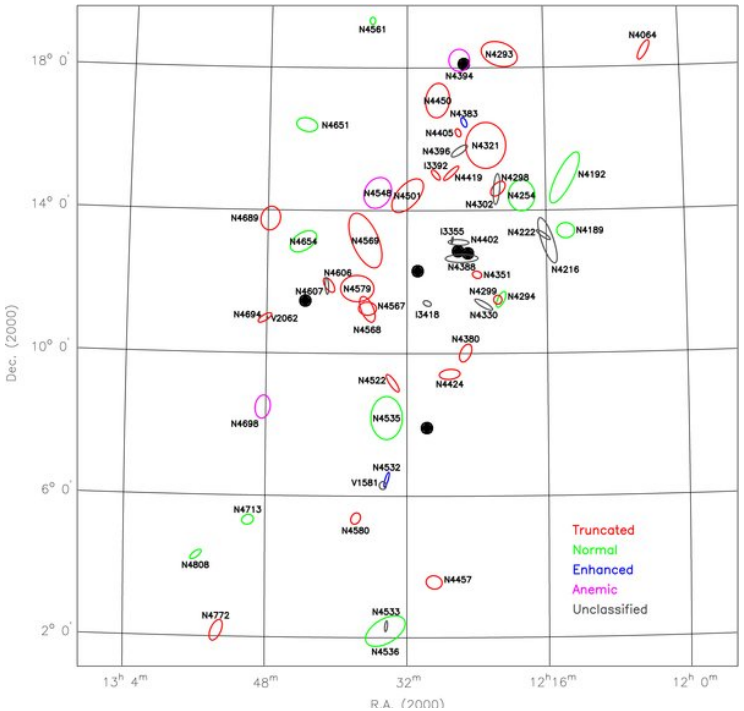
MeerKAT proposal Paolo Serra

The on-going assembly of Fornax

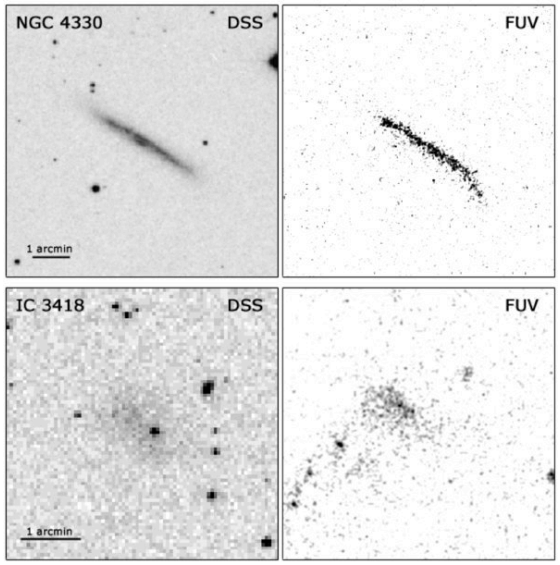
ASTRON

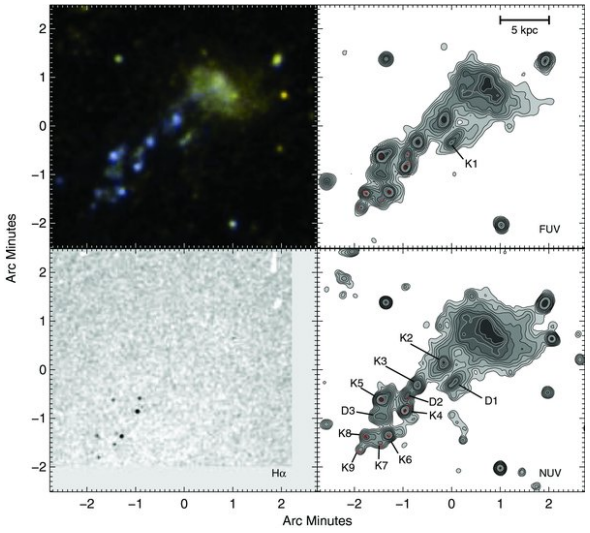


Limiting sensitivity 10^{18} cm^{-2} to be done in 2016



Two galaxies in VIVA sample selected for their UV images





Hester et al, 2010

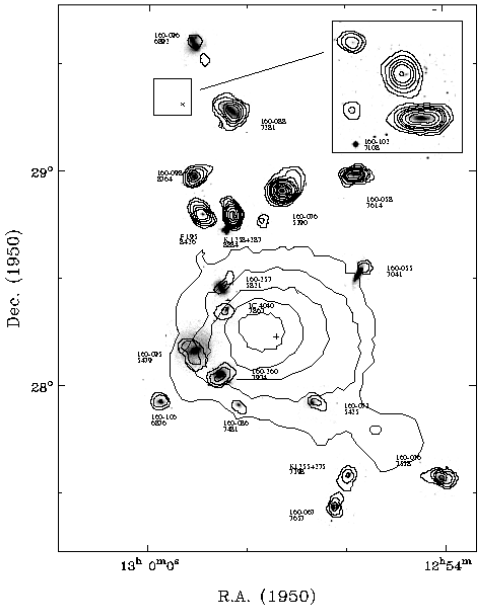
Gavazzi et al 2006

Imaging showing a 17 kpc tail of star formation trailing IC 3418 as it plunges through Virgo's ICM. Upper left: color composite ultraviolet image; FUV is blue, NUV is red, and the average UV intensity is green.

Tonnesen and Bryan 2010 discuss under what conditions tails light up in X-ray, H alpha or HI

Depends on ICM pressure

Note that Coma has lots of star forming tails Russell Smith talk



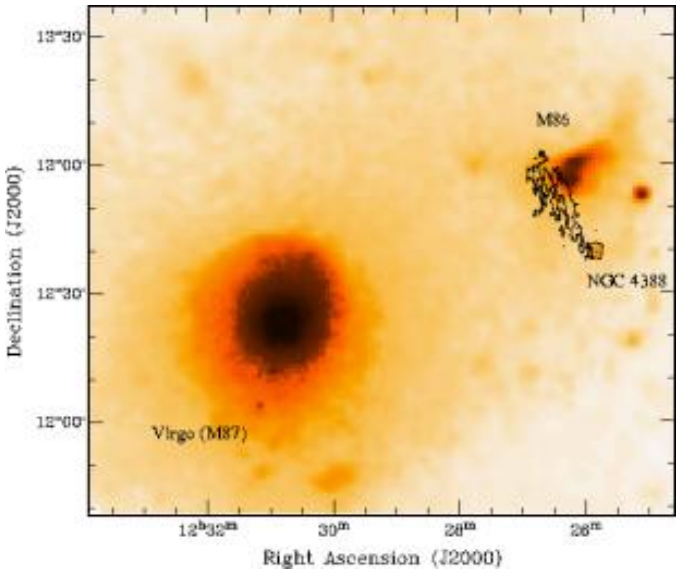
HI contours on DSS gray scale

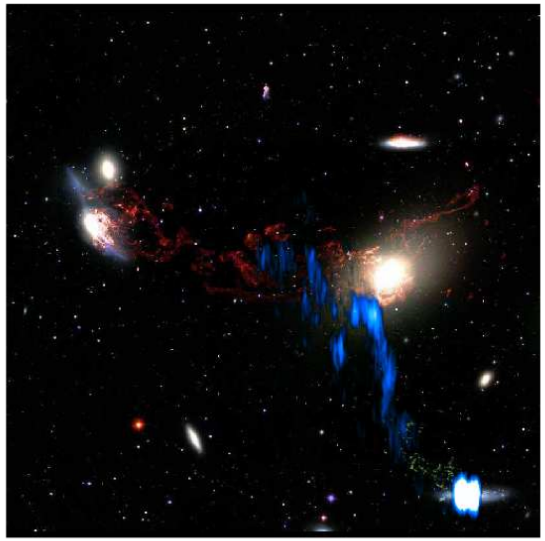
Large contours ROSAT

Bravo-Alfaro et al 2000

Much denser ICM.. No galaxies detected in center..

Near M86 we see gas in all phases, X-ray, H alpha, HI





Red, green H alpha Kenney et al 2008; blue HI Oosterloo & van Gorkom, 2005