Groups of Galaxies in the Nearby Universe

Summary: Ken Freeman

Goals of Summary

Overview of what we have learned

Identify some problems

1. LOCAL GROUP AND NEARBY GROUPS

GREBEL

50-75% of galaxies are in groups

The CDM problem (too many dwarf halos) is specific to the group environment, not to clusters

Local Group Content: ~ 38 galaxies: four significant spirals, rest dwarfs: mainly dIrr and dSph, plus a few dE.

Spatial segregation of dwarfs: gas-poor dwarfs mostly close to MW and M31, dIrr fill a much larger volume. Similar situation in M81, Cen A groups - usually interpreted as stripping.

The other nearby groups like M81, Cen A have ~ two bright galaxies + dwarfs. Crossing times ~ 3 Gyr, ZV surface ~ 1 Mpc, masses ~ 10^{12} M_sun. All have similar LF, rising gradually to M_B ~ -10.

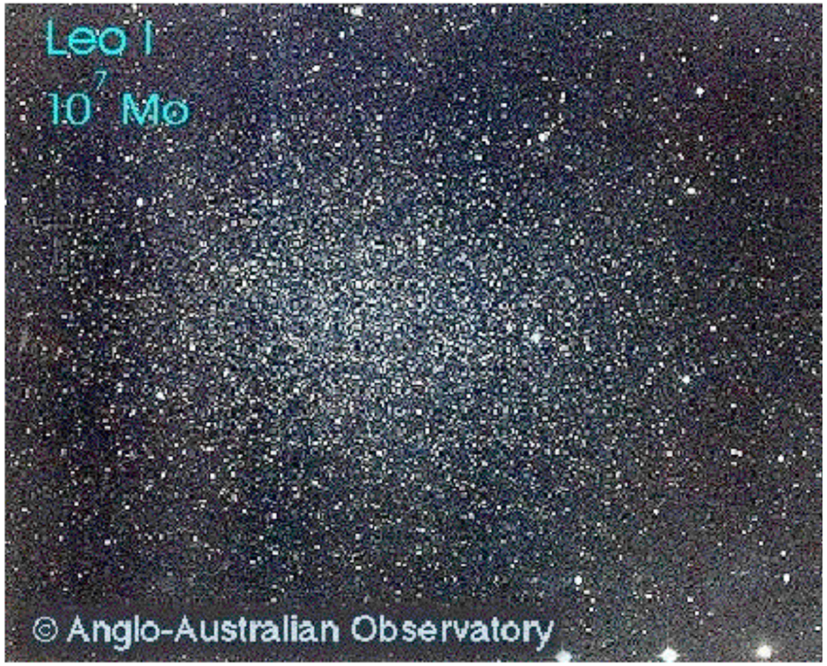
Stellar populations: All of these galaxies have an old population, straddling the EoR. The subsequent SFH varies greatly from galaxy to galaxy : most have extended SFH ranging over > 2 Gyr, going on to z~0.5 in many cases.

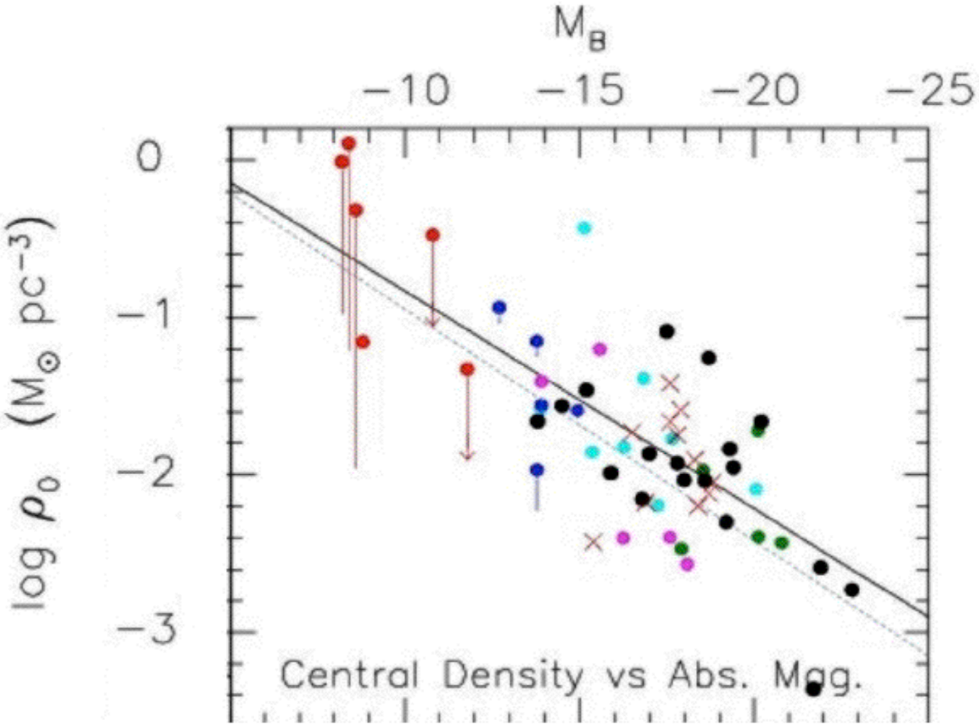
The [α/Fe]-[Fe/H] properties of the dSph are different from the galactic halo: if halo formed from accreted dSph, it must have been very long ago. GEISLER: In the Scl dSph, only the most metal poor stars have halo-like enhanced [O/Fe] and [Ba/Eu]. Could explain the low [α/Fe] for the rest of the stars via a low SFR and high galactic winds.

Two comments:

- Local Group is very unevolved. Turnaround was at $z < 0.7$. Least action solutions for galaxy orbits show how collapse has only just begun.

• dSph galaxies are not fragile. They have very dense halos and are just a little short on baryons.





Kormendy & Freeman 2003

dark halo density vs M_B

SKILLMAN: See trend of SFH with distance from massive galaxy for MW dwarfs (dSph, transition, dIrr), less so for M31. Attribute to interaction : radiative, gravitational, hydro ...

Estimating SFH in LG dwarfs: error control is essential.
All dwarfs have old stars, but much variety in SFH thereafter.
eg SFR in IC1613 peaked at about 5 Gyr. Reason for variety not understood

More similarities than differences in the SFHs for dSph and dIrr.

KORIBALKSI: 85% of galaxies within 10 Mpc are dwarfs.
Contribute 4% of light, 15% of HI.

Trace a very cold Hubble flow out to distance of at least 6 Mpc.

Spectacular HI data on M83 - tidal filaments out to diameter of 80 kpc. Stars are forming out there (GALEX). See how the group environment is reshaping the disk of M83 - its disk will soon be much more extended.

A major theme: evolution in the interactive group environment has great effect on the properties of galaxies in the universe.

PISANO: Are CHVCs the missing satellites ?

Around MW, expect 300 satellites. Know only 20, but there are ~ 270 CHVCs ! Search for CHVC counterparts in several nearby groups but none found.

Implication is that MW CHVCs lie within 100 kpc and have masses ~ 10^5 M_sun. Unlikely to have much to do with galaxy formation unless they have a lot of associated ionized gas.

Note similarity of the V_c distribution for CHVCs and LG galaxies to the CDM expectation, so could still be relevant to galaxy formation even though they are close in.

2. GROUP SEARCHES AND SURVEYS

EKE

What is a group ? Masses ~ $10^{12.5}$ to $10^{13.5}$ M_sun. Going to higher masses ($M > 10^{14}$, $\sigma > 400$ km/s) brings in different physics and dynamics: eg mergers and interactions reduced, harassment appears ...

Techniques for finding groups and clusters (a) without redshifts and (b) with redshifts from large catalogs like 2dF and SDSS.

Calibrate FoF algorithm on mock catalog from simulations.

The 2PIGG catalog shows that most of the stellar mass in the universe is in LG-sized aggregates with $M \sim 2.10^{12}$ M_{sun}, and only 2% in clusters with $M > 5.10^{14}$ M_{sun}.

POMPEI

DPOSS II survey: 459 candidate compact groups. Finds compact systems which may have been missed in 2dF/SDSS because of fiber placement restrictions. 60% confirmed spectroscopically as bound systems, mean $z = 0.13$. Typical $\sigma = 350$ km/s, similar to CG at $z = 0$ in M ($3.10^{12}\,M_{sun}$) and M/L (90).

Either there has not been much evolution from $z = 0.13$ to $z = 0$, or the evolution is very rapid and we see different CG now: seems likely.

CELLONE

In the rich NGC 5044 group, find early-type dwarfs with embedded spiral structure, bars, disks, dEn, dS0 ... and no clear spatial segregation between the different kinds of dwarfs.

Could be remnants of disk systems that have suffered interactions.

FORBES

The GEMS project - new X-ray, optical and HI observations of 60 groups at distances of 15-30 Mpc. Some results:

- no evidence for stripping of X-ray halos in groups
- R_{500} from T_X and σ are fairly similar
- see galaxies at group velocities well beyond R_{500} : filament galaxies
- composite group has flat sigma - higher spiral fraction at large R
- most isolated ellipticals are not collapsed groups

MIESKE

Search for UCD in nearby (10 Mpc) NGC 1023 group (σ = 60 km/s). Interesting because most mechanisms for generating UCDs dynamically predict few UCDs in the group environment.

At this distance, UCDs are marginally resolved. CFHT candidates with appropriate magnitudes and diameters are uniformly distributed over the field, consistent with background contamination.

HIBBARD

Spitzer observations of HCGs, to correlate with their HI-deficiency relative to field galaxies. Spitzer images are good SF and dust indicators.

Saw examples of SF and dust in HI-deficient group galaxies, decreasing to very weak PAH emission and little gas or X-ray emission in the most evolved groups.

Process of HI removal is not clear: could be ram pressure from halos, or photoionization by the brighter galaxies.

The mechanism for HI loss was a recurrent theme of the meeting.

GIOVANELLI

The ALFALFA Arecibo multibeam survey. Very exciting and powerful facility, order of magnitude more sensitive than HIPASS, with excellent spatial and velocity resolution.

Ideal for detecting low HI mass systems in groups within the local supercluster.

Has already blown away the ill-fated Virgo dark cloud. The high sensivity shows the cloud is just part of a tidal streamer associated with NGC 4254.

3. EVOLUTION OF GALAXIES IN GROUPS
(long section: many aspects)

CONSELICE

Evolution of galaxies in groups driven by interactions
σ = 100 - 400 km/s

Groups already present at $z > 1$ and beyond. Clustering signal comes from aggregates with σ = 100 - 400 km/s out to $z=1.4$
Groups contain more passive galaxies relative to field at all z.

Most stars formed between $z = 2.5$ and 1, so this is the main epoch of galaxy formation in groups, although we know that SF in Local Group galaxies started much earlier ($z \sim 10+$)

Mergers are main driver of evolution where $\sigma \sim \sigma_{internal}$.
Loss of gas probably not so important, because groups have many star-forming galaxies.

Expect ~2% of galaxies merge $(\mathrm{Gyr})^{-1}$, more important at higher z. (HDF dominated by peculiar galaxies; at z~2.5, about 50% of bright galaxies are undergoing mergers; merger rate drops rapidly for z<1).

Dwarfs probably attached to their groups already at high z (cf simulations)

COORAY

Growth of the brightest galaxies in groups is driven mainly by dry mergers: not much star formation at these masses

The maximum size of the brightest galaxies is regulated by hierarchical clustering and collisionless dynamics.

The origin of the maximum mass scale for BGG ($\sim 10^{12}$ M_{sun}) was a recurrent theme at the meeting

HAU CNOC2 sample of groups with z = 0.1 to 0.5. Use M/L from synthetic stellar populations to study evolution of total stellar mass in groups within r_{200}. Conclude that most of the stars were in place at z = 1, though the groups themselves are forming since z=1

WILMAN Study influence of group environment since z = 0.5 on galaxy morphology and SF. See decline in SFR, growth in number of passive spirals galaxies and development of red & dead population; more bright galaxies and bright S0s in groups than in the field. Building S0s from spirals means enhancing their bulges via dynamics or starbursts.

The growth of SOs and passive spirals in groups was an important theme of the meeting : associated with infall or interaction or maybe AGN activity.

CHIOSI

Formation of early type galaxies from cosmological initial conditions, including SF, heating and cooling of gas, chemical enrichment. Favors monolithic process, because most of the merging has gone on previously.

Most of stars are in place by z=2, though duration of SF is longer for lower mass systems. Rapid chemical enrichment. Products follow Sersic law. Argues that mergers are not the main route to early-type galaxies because they affect the colors for too long.

Also looked at evolution of small disk system in orbit around the MW. See transition from dIrr to dSph : round structure develops, much mass lost tidally. Many SF bursts, partly tidally driven and partly internal.

BOMANS

Photometric study of dwarf galaxy content of 5 nearby HCG. Find steep increase in the faint end of the LF.

The LF is bimodal - dwarfs populate the outer regions of the groups. HCG are plausible building blocks for dwarf-rich clusters.

The bimodality of the galaxy LF in compact groups came up several times at the meeting. Driven by the merger processes.

MARTINEZ

spectroscopic survey of Hickson CGs to find incidence of low luminosity AGNs. Find that > 50% of the galaxies have low luminosity AGNs, compared with ~ 30% in the field.

Suggests connection between nuclear activity and the gravitational interactions within the groups.

DE LA ROSA

Compare stellar populations of E galaxies in HCGs (22) and the field (12), via synthetic spectra.

Galaxies of intermediate σ are α-enhanced relative to the field, suggesting truncation of their SF as they enter the group.

The high-σ galaxies have a short duration of star formation anyway, so there is nothing to truncate.

LEE

Spitzer 4.5μ [m/H] - L relation for 25 nearby dwarfs including LG sample.

IRAC 4.5μ luminosity has low extinction and is dominated by older stars.

Tight [m/H] - M* relation indicates high level of regularity in galaxies' ability to retain enriched material as their potential wells vary in depth.

GOTO

Used 205 SDSS groups/clusters to study environmental effects on galaxy evolution.

For $R < 0.3\ R_{vir}$ see increase in fraction of E and decrease in fraction of S0s. Far out, at $R > R_{vir}$, see little change in morphology.

Passive spirals (no SF) are found in outer regions of clusters, where the density is between the cluster and the field density and where galaxies are falling into the cluster. These are probably transition objects between the blue spirals and the red S0s.

Some process is truncating the star formation in these outer regions of the clusters.

DA COSTA Stellar populations in dE of M81, Scl, Cen A groups. In the M81 dwarfs, AGB stars and presence of RGB clump provide evidence for intermediate-age population. None show only old stars. Diversity of the SFH is comparable to that of the LG dEs. Distribution in the [m/H]-L_V plane is like LG dE.

The reason for the diverse SFH in group dE not known. From their proximity to large spirals, environment must play some role.

One M81 group galaxy with a clump of young stars lies at the end of a gas streamer - could be a dE being transformed to a dIrr via gas torn tidally from M81.

REJKUBA Photometry of resolved stars in Cen A group dE again shows an extended SFH, from presence of AGB stars.

4. EVOLUTION OF GALAXIES IN GROUPS (THEORY)

MAMON

- Is group collapsing or virialized ? The inferred R, σ and M change as system evolves from Hubble expansion to turnaround, collapse and rebound. In the M_{vir}/L vs t_{cr} / t diagram, can see where the HCG and the loose groups lie.

- Frequency of formation of CGs is enough to explain the their existence - their short life is no problem.

- Relative importance of mergers driven by dynamical friction and by direct enounters. The merger rate peaks at masses near M* and radii near 0.1 R_{vir}. Major mergers in groups are dominated by direct mergers.

- How far radially does influence of groups extend ? See effects on morphology and *SFR out to ~2 R_{200}. Simulations agree: see group particles out to ~ 2.5 R_{100} (eg Gill et al)

- see offset in morphology-density relation between X-ray groups and clusters (groups are more spiral-weak), produced by the enhanced merger rate in groups.

MIHOS, RUDICK   Diffuse starlight in clusters. Groups fall in to the clusters - slow encounters within the groups unbind stars from the group members which are then stripped by the tidal field of the cluster. Can typically move ~ 30% of the galactic mass in this way. Provides a similar function to fast encounters in clusters which similarly loosen up the galaxies for subsequent stripping by the tidal field.

Simulations from cosmological initial conditions show how this works. ICL production comes in short discrete events associated with group accretion and group merging within the clusters.

Spectacular deep imaging of the Virgo cluster core shows filaments of ICL near M87 and the M84/M86 subgroup. PN searches informed by this imaging can provide the kinematics.

MOELLER

Theoretical study of prospects for determining matter distributions in groups via lensing ... distinguishing whether most of the mass is in galaxies or if there is a significant group halo.

Prospects for both weak and strong lensing observations. The weak lensing shear properties, and the caustic geometry for strong lensing, are sensitive to whether the halo mass is group-wide or distributed within the individual galaxies.

5. EVOLUTION OF GROUPS AS SYSTEMS

ZABLUDOFF

Groups have a range of evolutionary states, from LG at unevolved extreme to evolved high-σ groups with BGG and extended X-ray emission, and then to fossil groups. The fossils come mainly from the bright galaxies: process leaves X-ray gas and the dwarf population of the CG intact. Saw examples of some highly evolved groups from TEMPORIN and DURRET.

Mergers and gas loss drive the evolution in the range of σ for groups. Central galaxy grows, the dwarf/giant ratio increases, f (ET) increases, intragroup medium grows, common halo develops.

Merger process well understood.

The gas-loss process that leads to E+A systems, passive spirals and evolution of f (ET) is still mystery: ram pressure stripping disfavored by some. Is gas used up in SF, removed tidally or evaporated off through interactions.

Examples of group galaxies with extensive tidal structure, filaments, knots by KEMP, WEHNER and BRAVO-ALFARO.

These evolved systems fall into clusters or combine to form clusters, as in BROUGH's Eridanus supergroup.

They bring into the cluster many of the properties that we associate with the cluster environment: the X-ray medium, high dwarf/giant ratio, BGG, and the cluster-like f (ET) which is already seen in groups with $\sigma \sim 400$ km/s.

So the group processes are important for determining the properties of galaxies in the clusters.

Composite of several high- σ groups shows flat σ (R), indicating diffuse dm distribution, which also serves to reduce the merger rate and moderate the evolution of these groups.

The X-ray halo also has a component which is associated with the whole group and lies on the cluster L_X - T_X relation: the gas and galaxies trace the same potential.

The stars of the IG medium are particularly effective for chemically enriching the X-ray gas: no galactic potential well to overcome.

The morph-density relation is driven by brighter bulges in dense environments. Interactions in the group environment can provide this bulge growth.

Similarly the BO effect is probably driven by group processes.

The whole <u>downsizing</u> phenomenon may be associated with groups. A large fraction of galaxies are (or were) in groups at high z, and the group processes lead naturally to early truncation of star formation in the most massive galaxies.

PADILLA compare shapes of groups and clusters from 2PIGG and SDSS with groups in mock catalog constructed from dark matter simulations. Asphericity increases with mass and redshift. Good match between mock and real catalogs.

PLIONIS inversion of apparent shapes of 2PIGG groups shows that they are clearly prolate, again in agreement with dark matter s imulations.

MURIEL finds an extreme tilt of the FP for groups and clusters. This is very interesting: may give some unexpected insights into group structure and dynamics.

RAYCHAUDHURY

X-ray-bright groups have Schecter LF, while X-ray faint groups show marked bimodal LF, accentuated in cores. Indicates that merging activity is more important in these low-sigma groups.

Star formation is enhanced in groups lying within supercluster filaments, relative to field. SF is further enhanced as groups stream down filaments, well outside the virial radius of the groups.

6. INTERSTELLAR AND INTRAGROUP MEDIUM

PONMAN

Simple picture of gas falling spherically into group and shock-heating to virial temperature is too simple.

Complications include hierarchical rather than monolithic infall, interaction of galaxies and generation of hot gas at their interfaces (eg Antennae), feedback and cooling.

The baryon budget: at z=2 to 4, see the BBNS baryon density in Ly-α clouds, $T \sim 3.10^4$ K : filamentary structure, photoionized by stars and AGNs. At lower z, most of this gas is shock-heated in the filaments : $T \sim 10^5$ to 10^6 K. Difficult to detect: seen in OVI, OVII absorption.

In collapsed groups, see virialised gas in emission, even in some low-σ groups. Some HI seen outside the galaxies (KILBORN) probably tidally stripped from galaxies, but only small fraction of the gas that should be there. The L_X - σ relation for *optically* selected groups shows some groups with L_X lying well below the sequence for X-ray-selected groups: their gas may be in the WHIM phase.

For the hot gas, expect from self-similarity that $L_X \sim T^2$, but see $L_X \sim T^3$ in clusters, and even steeper in groups. Lower mass systems have higher entropy than expected: associate this with energy injection from SNe or AGNs (argue against AGNs) - probably in the filaments at early times.

The gas stripping process: one example suggests that the gas is pumped up by star formation and then removed by stripping : so stripping could occur even in low-sigma groups.

More on the HI-stripping theme ...

FREELAND: HI in groups with a range of f (spirals) : see evidence of tidal stripping. In less evolved groups, the HI detections are primarily near the center. In the more evolved groups, the detections are out at larger radii. The HIMF in groups is flatter than in the field : some process is depleting the HI at the low mass end.

KILBORN: Examples of tidally affected HI in group galaxies in groups with range of X-ray properties. See some very HI-deficient spirals in NGC 1566 group which has no detected hot IGM - argues against ram pressure stripping.

In loose groups, HI lies mainly in the galaxies. Some intracluster clouds are seen - likely tidal origin. The HI mass in groups anticorrelates with the intra-group T_X.

RASMUSSEN Fe and Si abundances of hot gas in groups with undisturbed morphologies.

- no [Fe/H] - T_X relation
- small central Fe-enhancement, declining to $0.1z_{sun}$ at large R
- Si/Fe is near-solar everywhere except at large R, where the gas is α-enhanced: ie solar balance of SNII/SNIa everywhere except at the largest R

GASTALDELLO Distribution of T_X and total mass in sample of X-ray groups with undisturbed morphologies. Find very similar T_X (R) relation. The total M(R) relation is close to NFW but more concentrated than predicted by simulations. Points to early-forming relaxed systems

O'SULLIVAN The cores of X-ray groups are often disturbed. Evidence for AGN feedback, enough in some to reheat the core against cooling ($t_{cool} \sim 10^8$ years). Disturbed cores affect use of X-ray gas as hydrostatic tracer of total mass

ROYCHOWDHURY The problem of the L_X - T_X and S - T_X relations for groups not following the expected gravitational scaling laws. Invoke AGN energy input to explain the excess entropy: heating via buoyant bubbles.

There is a relationship between excess entropy and presence of radio-loud AGNs in groups.

CORTES   Imaging and kinematics of peculiar galaxies in the Virgo cluster, in context of the spiral -> S0 transformation in clusters. What is the process ?

See great variety of structural and kinematcial disturbances. Hope to understand them in terms of ISM stripping and gravitational interactions

VERDES-MONTENEGRO

ISM in isolated galaxies vs compact groups. The AMIGA project: sample of ~ 1000 isolated galaxies with multi-λ observations. Contrast the properties of galaxies in these two extreme environments.

Goal is to understand the fate of the HI in stripped galaxies.

CGs show wide range of HI properties, from HI in galaxies -> tails and bridges -> HI outside the galaxies -> little HI anywhere. Occurence of HI stripping in CG is clear.

New data: most galaxies in CG are HI-deficient; FIR and CO deficiency goes with the HI-deficiency. In some, the HI deficiency ~ mass in hot gas.

JELTEMA X-ray selected groups at z=0.2 to 0.6. The (L_X, T_X, σ, S) relations are similar to those for low-z groups, *but*

- some show BGG with multiple components
- some don't have central early-type galaxy, and
- some are spiral-rich

all of which are unusual at low-z for groups with similar L_X

MAZZOTTA X-ray properties of mass-selected groups from 2PIGG: large systems with M = (3-6).10^{14}. About 70% are detected in X-rays, mostly with $T_{dyn} \sim T_X$. For the rest, the mass may have been overestimated or they are non-virialized systems.

BORGANI

Cosmology with clusters:
power of the $M\text{-}T_X$, $M\text{-}L_X$ distributions for clusters to give useful constraints on (Ω_m , σ_8).

Need to have the systematics of the models under control : requires good knowledge of the IGM/ICM physics, including merging

ANDERNACH

Association of CGs and large scale structure

Evidence that CGs form after the formation of larger scale structure. Comparison of CG and cluster samples suggests that

- most CG at $z \sim 0.15$ could be associated with larger structures
- galaxies in CG associated with larger structures are more evolved morphologically

ROMANOWSKY

Measuring the total mass distribution in ellipticals in different environments

Use PN, globular clusters, X-rays to probe the potential Different density distributions and anisotropies for the different stellar probes. In M87, the X-rays and globular clusters give similar M(r).

Globular cluster data in NGC 1399 now reaches to $10r_e$

Lot of kinematical data coming on L* ellipticals