# The Association of Compact Groups of Galaxies with Large-scale Structures

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- Groups of galaxies = principal environment of most galaxies in the Universe, but …
  their origin & evolution is still poorly understood
  (e.g. resolution of simulations is still insufficient)

- Important questions (Hierarchical Structure Formation):
  - When do they form? Suppose biased galaxy formation
    ➔ is there a "downsizing" effect for groups ?
    (high-mass groups at high z form first,
    then lower-mass groups at lower z)
  - What is the role of groups in the formation of larger structures? How long can a group retain its dynamical characteristics when merging with other groups to form larger structures?
  - What is the importance of groups for the formation and evolution of galaxies in large-scale structures?

- Observationally, the intrinsic low richness of groups makes them more difficult to detect than richer systems like cluster of galaxies, especially at intermediate and high redshift.
- Easier to detect: Compact Groups of Galaxies (CGs)
    1. Small mass systems (formed of 4 to 8 galaxies)
    2. High spatial overdensities (comparable to clusters)
    3. Low velocity dispersions (<<1000 km/s)
- Recent efforts to form "objectively" selected samples of CGs at low and intermediate redshifts (e.g. SCGs, SDSS-CGs and PCGs)

→ Goals of our study: relation of CGs with large scale structures

- Differences between selection algorithms,
  e.g. eye vs automatic
- The nature of association of CGs with large scale structures:
  flukes in selection method or real dynamical "substructures"?
- Variation with redshift: observational biases or evolution?

# Previous Studies:

- **Rood & Struble (1994): enviro of HCGs (low redshift, z ~ 0.04) out to about 2 Abell radii:**
  - **some HCGs are associated with Abell rich clusters, and**
  - **many more (~2/3) with poorer systems ("Loose Groups")**

  **→Although CGs are "isolated dynamical systems" their formation must be related to the formation of the large-scale structure**

- **It is not clear if CGs associated with large-scale structures form real dynamical substructures or transient compact configurations** **(**Diaferio, Geller & Ramella 1994, Governato, Tozzi & Cavaliere 1996; Mamon 1986; Walke & Mamon 1989**)**

Different studies on the association of CGs with larger-scale structures at low redshift suggest that groups form after the formation of larger structures:

1. West (1989): clusters of galaxies exhibit a tendency to align with their neighbors on scales ~15-30 $h^{-1}$ Mpc ➔ massive structures formed before low-mass ones

2. Einasto et al. (2003): Loose Groups in the neighborhood of rich clusters seem more massive and luminous than groups on average ➔ their formation process depends on those of the more massive systems?

3. Coziol, Brinks & Bravo Alfaro (2004): galaxies in CGs associated with massive structures seem more evolved, in terms of morphology and level of activity, than those in CGs associated with lower-mass structures

➔ difference in time of formation (global effect) or difference in the rate of galaxy evolution (local effect)?

# Samples used in our study

- **Compact groups:**

  - 100 Hickson Compact Groups, HCGs (Hickson 1982)
  - 121 Southern Compact Groups, SCGs (Iovino 2002)
  - 459 Palomar Compact Groups, PCGs (deCarvalho et al. 2005)
  - 177 SDSS Compact Groups, SDSS-CGs (Lee et al. 2004)

- **Associated Large-Scale Structure:**

  - Abell clusters: 5250 clusters (Abell/ACO + suppl. S-clusters; most recent compilation of z's (Andernach & Tago, >3000 z's)
  - Northern Sky Optical Cluster Survey Catalog, NSC (Gal et al. 2003); only poor photometric redshifts
  - Loose groups: UZC-SSRS2 group catalog (Ramella et al. 2002); all with known (low) redshifts

# Comparison Abell vs NSC clusters

NSC clusters not associated with Abell clusters are poorer:

| Number of galaxies | $N_{gal}$(NSC) (non-assoc) | $N_{gal}$(NSC) (Abell-assoc) |
|---|---|---|
| mean | 29 | 43 |
| median | 30 | 41 |

NSC reach slightly higher redshifts than the Abell sample:

| Redshifts | NSC | Abell |
|---|---|---|
| mean | 0.1616 | 0.1541 |
| median | 0.1565 | 0.1468 |

NSC does not include smaller structures similar to loose groups: incompleteness at redshift $z \sim 0.1$ could be as high as 70% according to NSC authors (Gal et al. 2003).

# Method

- Association with Abell clusters: if projected distance from CG to ACO center is <1 Abell radius of the cluster (Abell radius = 1.5 $h^{-1}$ Mpc, with $H_0$ = 100 $h^{-1}$ km $s^{-1}$ $Mpc^{-1}$);

- Association with NSC and UZC-SSRS2: cross-correlation of the latter catalogs with CG catalogs available at Strasbourg Data Center (CDS, Vizier) within one Abell radius.

- **Confirming the associations:**

a) Visual inspection on DSS2 images from *Aladin* (aladin.u-strasbg.fr)

b) Comparing redshifts:

✓ HCGs (Hickson et al 1992) and SDSS-CG (Lee et al. 2004);

✓ SCGs, mean value of galaxies included in NED;

? PCGs, very few redshifts available (finding charts were not published);

# Type of association

From our visual inspection, we classify the type of association that CGs may have with the larger systems; depending on

a) projected distance of the group relative to the center of its associated structure and

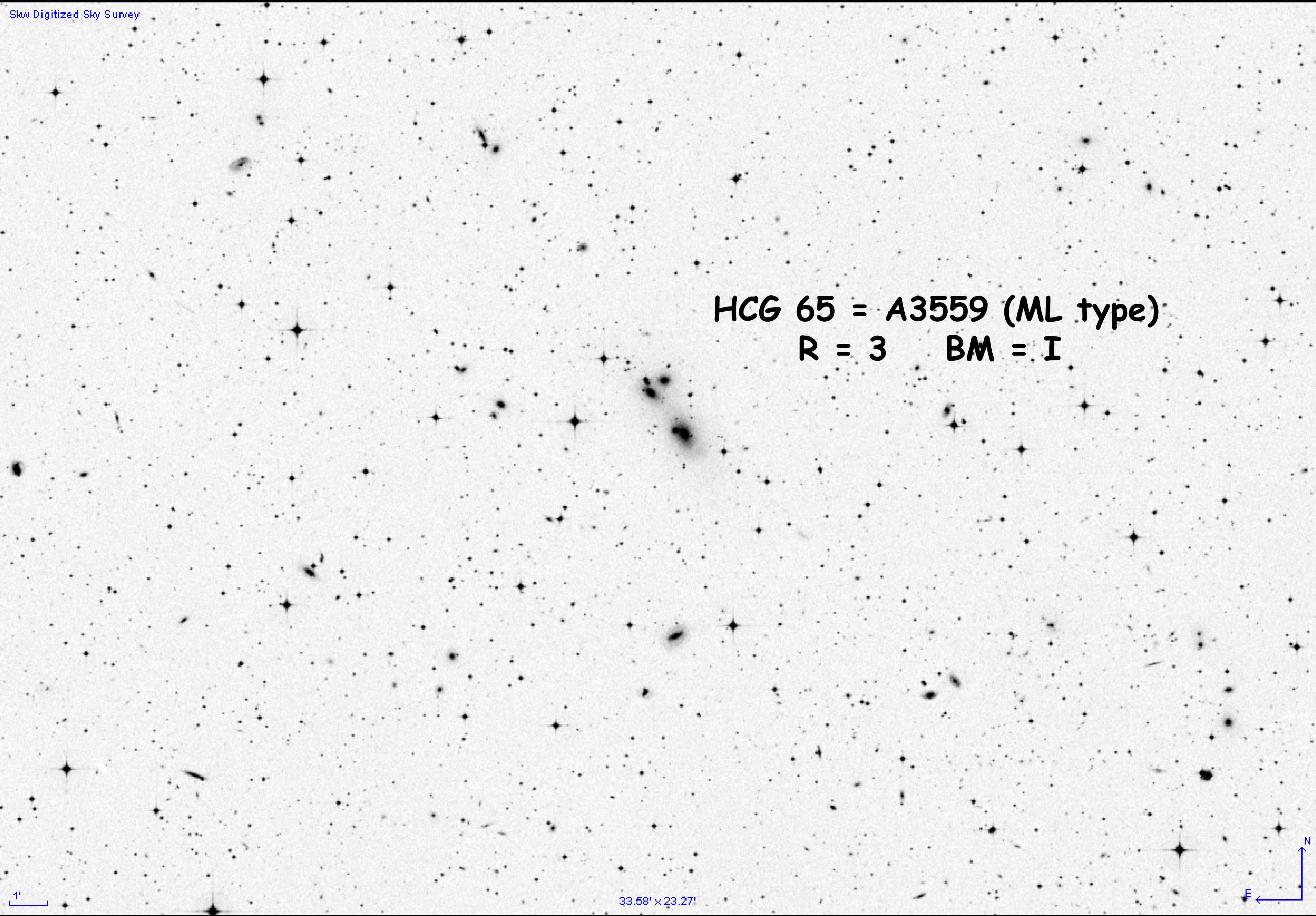
b) relative apparent magnitudes of the galaxies in the two structures

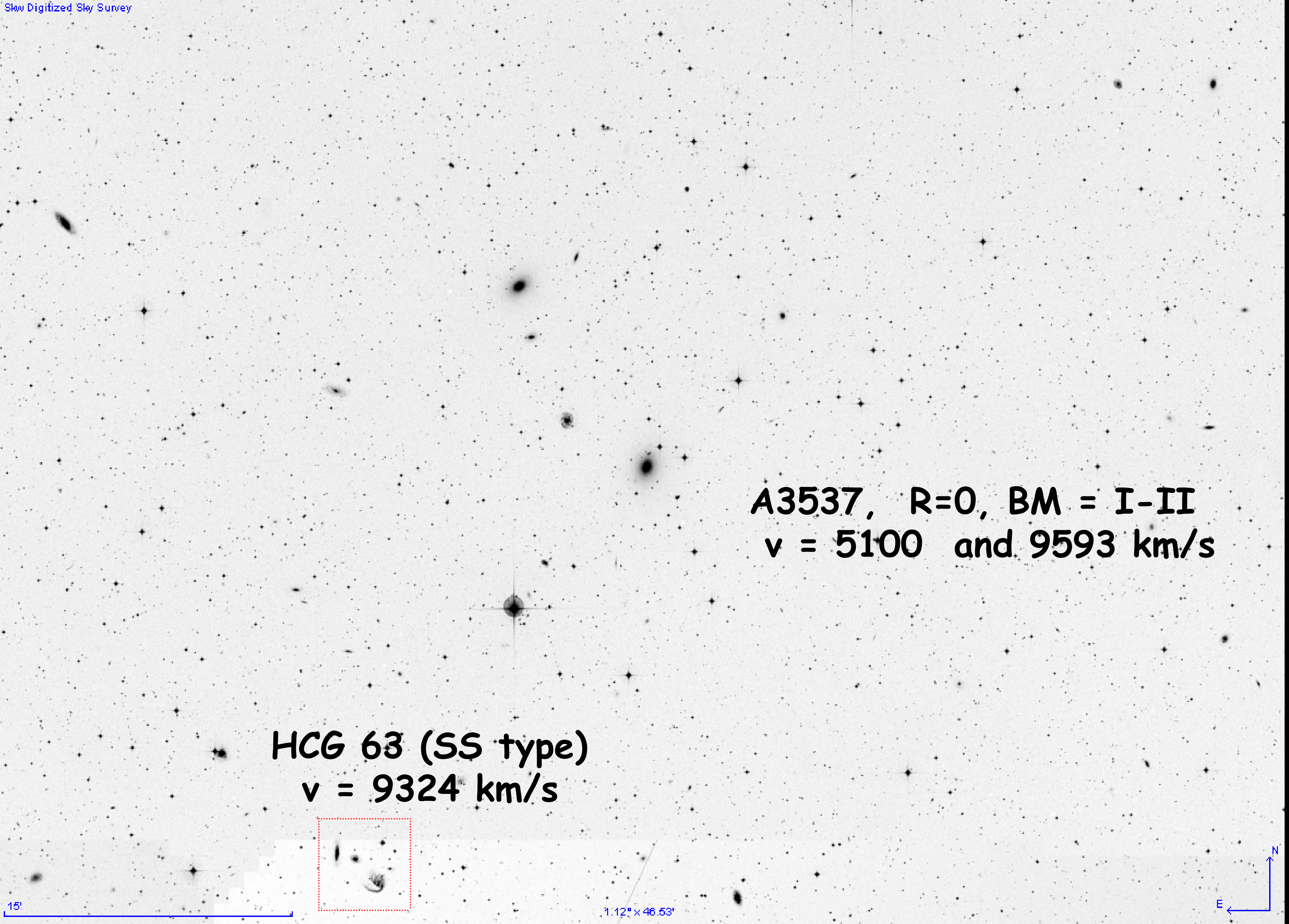
➔ we distinguish three classes of apparent association:

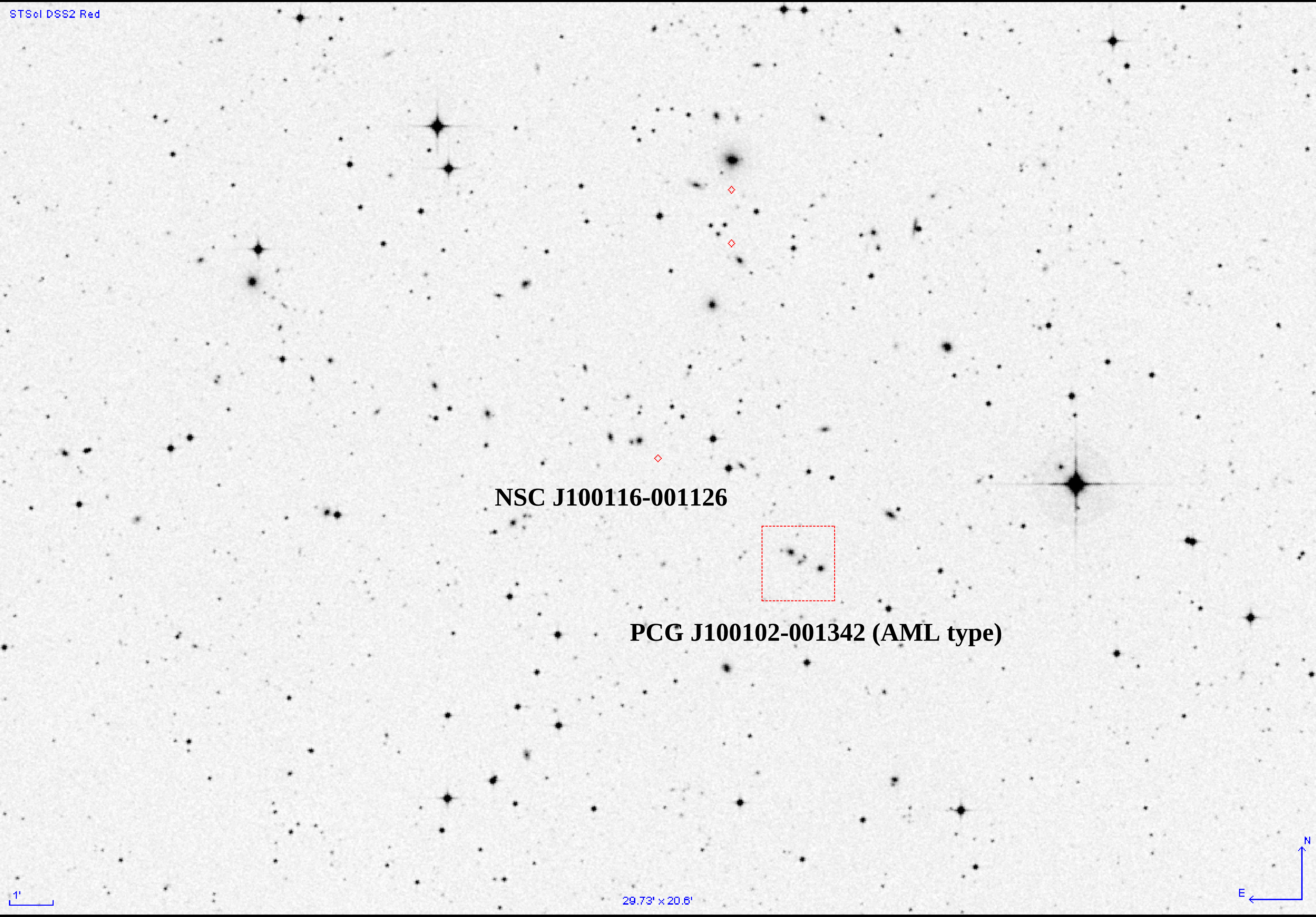
1) SS: CGs are not cluster-centric; seem to form "*substructure*"; CG galaxies are either fainter or as luminous as the brightest galaxies in the larger system;

2) ML: CG forms main structure itself (centric position); CG members are the "*most luminous*" of entire system

3) AML: CG members are part of the main structure; galaxies are "*among the most luminous*" of the system


Skw Digitized Sky Survey
HCG 65 = A3559 (ML type)
R = 3 BM = I
1'
33.58' x 23.27'
N
E


Skw Digitized Sky Survey
A3537, R=0, BM = I-II
v = 5100 and 9593 km/s
HCG 63 (SS type)
v = 9324 km/s
15'
1.12° x 46.53'
N
E



STScI DSS2 Red
NSC J100116-001126
PCG J100102-001342 (AML type)
1'
29.73' x 20.6'
N
E

# Association with Abell clusters

| | N | % | $\langle z \rangle$ | Ass. type | | | R | | | | BM | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | SS | ML | AML | 0 | 1 | 2 | 3 | undef. | Early | Late |
| HCG | 6 | 6 | 0.04 | 5 | 1 | ... | 5 | ... | ... | 1 | ... | 2 | 3 |
| SCG | 21 | 17 | 0.04 | 9 | 12 | ... | 18 | 2 | 1 | ... | 2 | 14 | 5 |
| PCG | 71 | 17 | 0.12 | 20 | ... | 51 | 23 | 34 | 12 | 3 | 12 | 5 | 54 |
| SDSS | 16 | 9 | 0.12 | 11 | ... | 5 | 5 | 9 | 1 | 1 | 4 | ... | 12 |

**Difference in method:**

- HCG vs SCG: eye selection reduces number of CG-LSS associations: 83% SS type in HCGs vs 57% ML in SCGs.
- SDSS vs PCG: 69% SS type in SDSS vs 72% AML in PCGs (why only 1 SDSS-CG coincides with a PCG ? Expect ~10)
- Association rate is similar at low & intermediate z, BUT :

  a) Richness of associated clusters rises with z: fraction of R ≥ 1 cluster rises: 14% SCGs to 69% (PCGs & SDSS)

  b) BM type changes with z: from 74% early (I, I-II and II) in SCGs to 92% late (II-III, III) in the PCG and 100% "late" in the SDSS.

# Variation of Abell cluster richness with z

| | $z=0$ | $z=0.05$ | $z=0.1$ | $z=0.15$ | $z=0.2$ | $z=0.25$ | $z=0.3$ | $z=0.35$ |
|---|---|---|---|---|---|---|---|---|
| | | | | number of clusters | | | | |
| $R=0$ | 31 | 769 | 789 | 592 | 188 | 33 | 7 | 1 |
| $R=1$ | 3 | 118 | 383 | 953 | 462 | 52 | 7 | 0 |
| $R=2$ | 1 | 36 | 95 | 281 | 260 | 46 | 9 | 0 |
| $R=3$ | 0 | 5 | 6 | 37 | 57 | 16 | 2 | 1 |
| $R=4$ | 0 | 1 | 0 | 0 | 6 | 1 | 0 | 0 |
| | | | | frequency per bin | | | | |
| $R=0$ | 0.89 | 0.83 | 0.62 | 0.32 | 0.19 | 0.22 | 0.28 | 0.5 |
| $R=1$ | 0.09 | 0.13 | 0.30 | 0.51 | 0.47 | 0.35 | 0.28 | 0 |
| $R=2$ | 0.03 | 0.04 | 0.07 | 0.15 | 0.27 | 0.31 | 0.36 | 0 |
| $R=3$ | 0 | 0.01 | 0 | 0.02 | 0.06 | 0.11 | 0.08 | 0.5 |
| $R=4$ | 0 | 0 | 0 | 0 | 0.01 | 0.01 | 0 | 0 |
| | | | | expected increase for constant density | | | | |
| | | 26.00 | 3.77 | 2.22 | 1.77 | 1.56 | 1.44 | 1.36 |
| | | | | observed increase | | | | |
| $R=0$ | | 24.81 | 1.03 | 0.75 | 0.32 | 0.18 | 0.21 | 0.14 |
| $R=1$ | | 39.33 | 3.25 | 2.49 | 0.48 | 0.11 | 0.13 | |
| $R=2$ | | 36.00 | 2.64 | 2.96 | 0.93 | 0.18 | 0.20 | |
| $R=3$ | | | 1.20 | 6.17 | 1.54 | 0.28 | 0.13 | 0.50 |
| $R=4$ | | | | | | 0.17 | | |

From z = .02 to .1 the frequency of poor ACO clusters with R=0 decreases only by factor of 1.3.

… while CG-associated R=0 ACO clusters decrease by factor of 6 passing from SCGs to PCGs.

Fraction of ACO clusters with R >=1 rises only by a factor of 2.

… while CG-associated ones rise by factor of 5 from SCGs to PCGs

Increase in richness of the PCG-associated ACO-clusters at intermediate z cannot be explained by an incompleteness of the Abell/ACO sample.

# Variation of BM types with z

| | $z=0$ | $z=0.05$ | $z=0.1$ | $z=0.15$ | $z=0.2$ | $z=0.25$ | $z=0.3$ | $z=0.35$ |
|---|---|---|---|---|---|---|---|---|
| | | | | number of clusters | | | | |
| I | 15 | 152 | 85 | 57 | 44 | 5 | 0 | 0 |
| I-II | 7 | 236 | 188 | 133 | 74 | 17 | 0 | 0 |
| II | 5 | 292 | 244 | 230 | 133 | 23 | 2 | 1 |
| II-III | 4 | 96 | 259 | 370 | 227 | 45 | 4 | 0 |
| IIII | 4 | 121 | 290 | 721 | 443 | 54 | 18 | 1 |
| | | | | frequency per bin | | | | |
| I | 0.43 | 0.17 | 0.08 | 0.04 | 0.05 | 0.03 | 0 | 0 |
| I-II | 0.20 | 0.26 | 0.18 | 0.09 | 0.08 | 0.12 | 0 | 0 |
| II | 0.14 | 0.33 | 0.23 | 0.15 | 0.14 | 0.16 | 0.08 | 0.5 |
| II-III | 0.11 | 0.11 | 0.24 | 0.24 | 0.25 | 0.31 | 0.17 | 0 |
| IIII | 0.11 | 0.13 | 0.27 | 0.48 | 0.48 | 0.38 | 0.75 | 0.5 |
| | | | | frequency per bin | | | | |
| early | 0.77 | 0.76 | 0.48 | 0.28 | 0.27 | 0.31 | 0.08 | 0.5 |
| late | 0.23 | 0.24 | 0.52 | 0.72 | 0.73 | 0.69 | 0.92 | 0.5 |

ACO sample @ z~0.1 composed of 48/52 % early/late BMs.
→ ~ 50-50 chance to find early or late BM type at this redshift.

Indeed we find not one CG-associated ACO cluster of BM I or I-II @ z~.1.
This is despite the equal detection probabilities for early & late BM types.

**→ preference of late BM types for CG-associated clusters at intermediate z is not due to a selection effect in the ACO sample.**

# Association of CGs with poorer structure

## Associations with UZC-SSRS2:

| | N | % | $\langle z \rangle$ | Ass. type SS | ML | AML | $\langle N \rangle$ |
|---|---|---|---|---|---|---|---|
| HCG | 37 | 37 | 0.02 | 2 | 30 | 5 | 6 |
| SCG | 33 | 27 | 0.02 | 8 | 22 | 3 | 8 |

Rate of associations rises w.r.t. cluster-associations:

factor 6 for HCG and
2 for SCG
factor 4 for PCG and
3 for SDSS

## Associations with NSC:

| | N | % | $\langle z \rangle$ | Ass. type SS | ML | AML | $\langle N \rangle$ |
|---|---|---|---|---|---|---|---|
| PCG | 195 | 62 | 0.13 | 55 | 10 | 130 | 35 |
| SDSS | 21 | 25 | 0.13 | 5 | ⋯ | 14 | 40 |

Given the incompleteness, most CGs could be associated with larger structures at intermediate redshift.

Majority are ML or AML type
➔ CGs form important components of structures.

# Possible interpretation

- ✓ Variations with redshift of Abell richness, association type and BM type are consistent with an increase of mass of the associated structures at intermediate redshift.

No obvious evidence of observational bias for richness or BM type
(no sufficient decrease of poorer ACO or NSC cluster density
seen out to z = 0.1;
early/late BM types = 50/50 at z = 0.1 in ACO)

Same trend is observed despite the differences introduced by the selection methods

➔ general phenomenon ?

- ✓ Association types ML and AML more frequent at intermediate z and in poorer structures

➔ CGs may generally form an important "substructure" of the associated larger-scale structure.

# Evolution of galaxies in CGs: morphological type distribution

**Types from CDS catalog VII/213**

**HCG**

| Morph. | HCG out of Cl. $N_{gal}$ | % | HCG in LG. $N_{gal}$ | % | HCG in cl. $N_{gal}$ | % |
|---|---|---|---|---|---|---|
| Early | | | | | | |
| E | 55 | 21.1 | 37 | 23.7 | 10 | 38.5 |
| S0 | 75 | 28.7 | 27 | 17.3 | 7 | 26.9 |
| S0/a | 12 | 4.6 | 9 | 5.8 | 0 | 0 |
| Intermediate | | | | | | |
| Sa | 13 | 5.0 | 13 | 8.3 | 0 | 0 |
| Sab | 6 | 2.3 | 5 | 3.2 | 1 | 3.8 |
| Sb | 14 | 5.4 | 10 | 6.4 | 1 | 3.8 |
| Late | | | | | | |
| Sbc | 11 | 4.2 | 9 | 5.8 | 0 | 0 |
| Sc | 36 | 13.8 | 23 | 14.7 | 5 | 19.2 |
| Sd/Sdm/Ir | 39 | 14.9 | 23 | 14.7 | 2 | 7.7 |

**Types from NED (brightest ~37% galaxies)**

**SCG**

| Morph. | SCG out of Cl. $N_{gal}$ | % | SCG in Cl. $N_{gal}$ | % |
|---|---|---|---|---|
| Early | | | | |
| E | 16 | 10 | 8 | 23.5 |
| S0 | 47 | 29.4 | 13 | 38.3 |
| S0/a | 9 | 5.6 | 1 | 2.9 |
| Intermediate | | | | |
| Sa | 20 | 12.5 | 2 | 5.9 |
| Sab | 9 | 5.6 | 2 | 5.9 |
| Sb | 20 | 12.5 | 3 | 8.9 |
| Late | | | | |
| Sbc | 11 | 6.9 | 1 | 2.9 |
| Sc | 21 | 13.1 | 1 | 2.9 |
| Sd/Sdm/Ir | 7 | 4.4 | 3 | 8.8 |

- Galaxies in CGs associated with larger scale structures are more evolved morphologically ➔ associations are physically real
- High number of early-type in isolated CGs ➔ CG favor evolution
- No difference between isolated and loose groups ➔ threshold in density or difference in formation time?

# Cautionary notes on automated (compact) group detection

While inspecting DSS images of PCGs we noticed "doubtful" cases
→ we inspected ALL 459 PCG images of DSS (not contained in deCarvalho et al. 2005, contrary to author's statement)

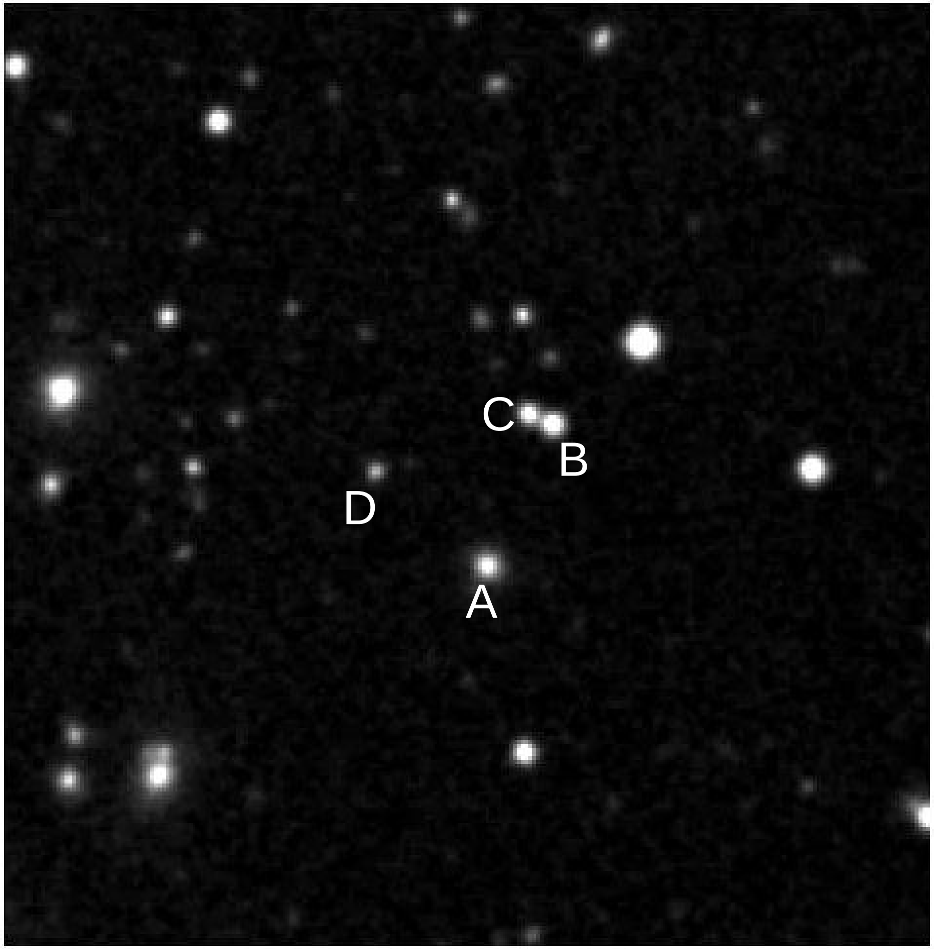
We found 52/459 (11%) of PCGs likely contaminated with stellar images (MANY confirmed by negative *g*-r colors as listed by authors themselves in their table of members)

SDSS-CGs have very different morphology than PCGs, many look like single galaxies with rather "insignificant" satellites → Do they represent the same type of objects?

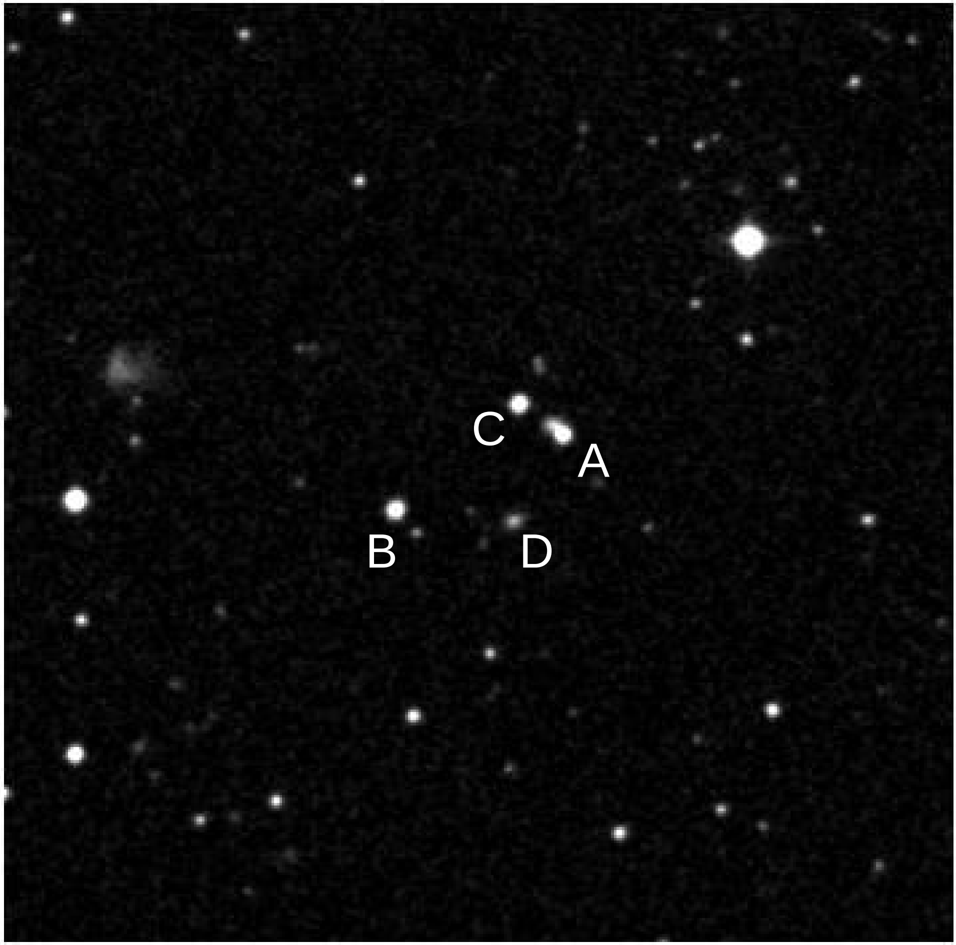
The 2dF "group" catalogue (V. Eke et al. 2004) contains several dozen rich Abell clusters ($N_{mem}$ >~ 100)

**PCG J164047+324843**
**B and C starlike**

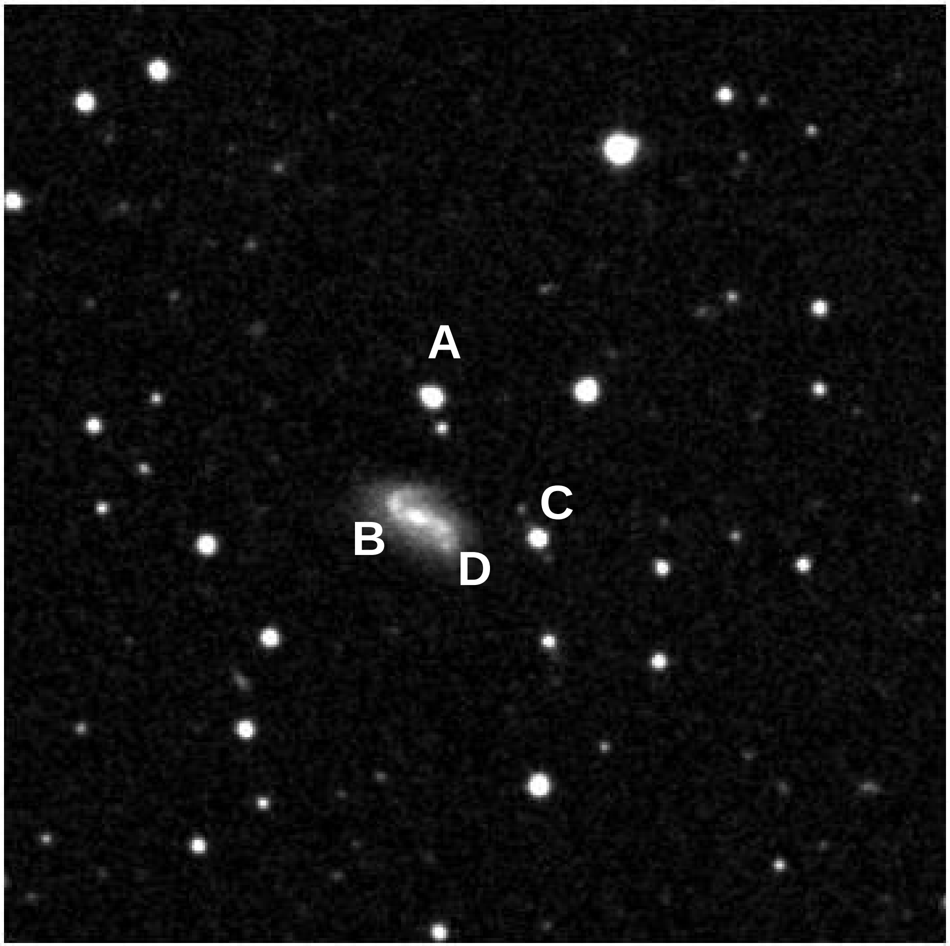
**Cluster NSC J164051+324856**
**at left edge of image**



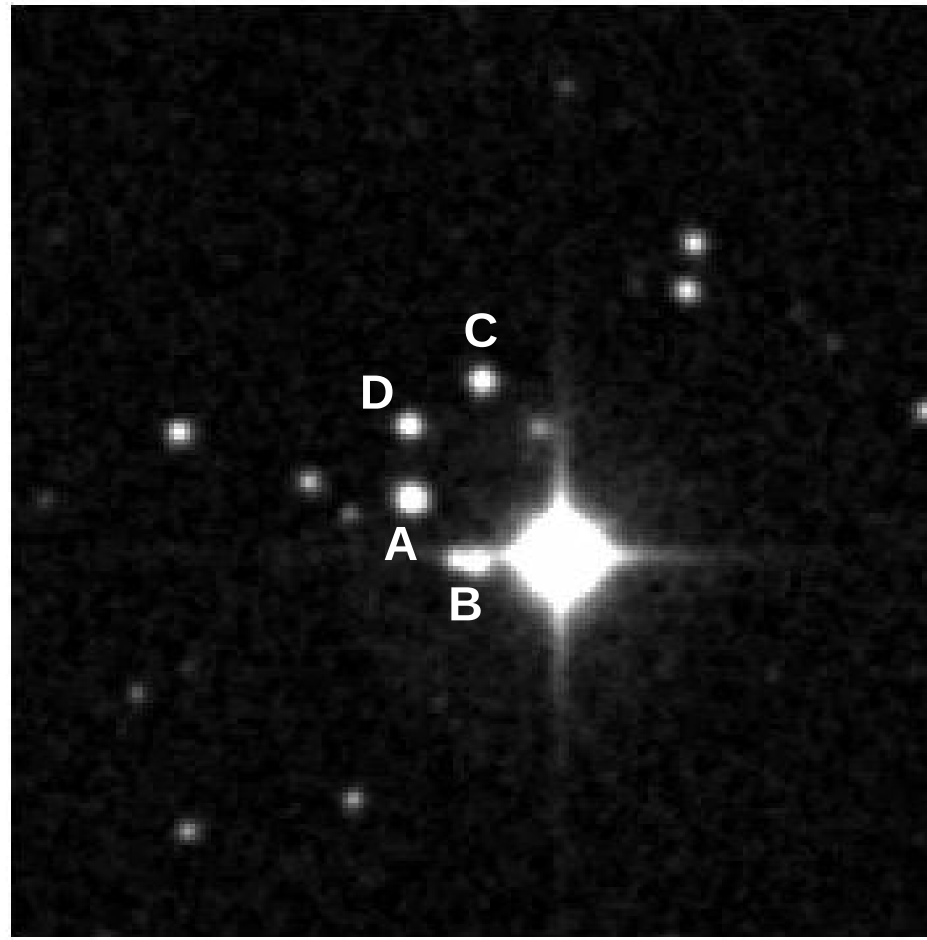

**PCG J154942+173434**
**A,B,C are starlike with**
**negative colors**



**PCG J1617+2041**
**B+D = part of MCG +04-38-044**
**(v = 9027 km/s)**
**A and C starlike**




**PCG J1618+4028**
**B (extreme color) right on a diffraction streak of star**



# Conclusions

We should return to a clear terminology differentiating between poor groups, compact groups, loose groups, clusters, rich clusters… (or else use terms like "overdensities")

Visual inspection of automatically "detected" groups is mandatory.

CG could play an important role in the formation and evolution of large scale structures and in the evolution of galaxies in these structures. This would be consistent with the actual paradigm of Hierarchical Structure Formation.

The variation in R and BM-type we observe from to medium z may also be consistent with biased galaxy formation.

For other evidence in favor of this model see two posters:

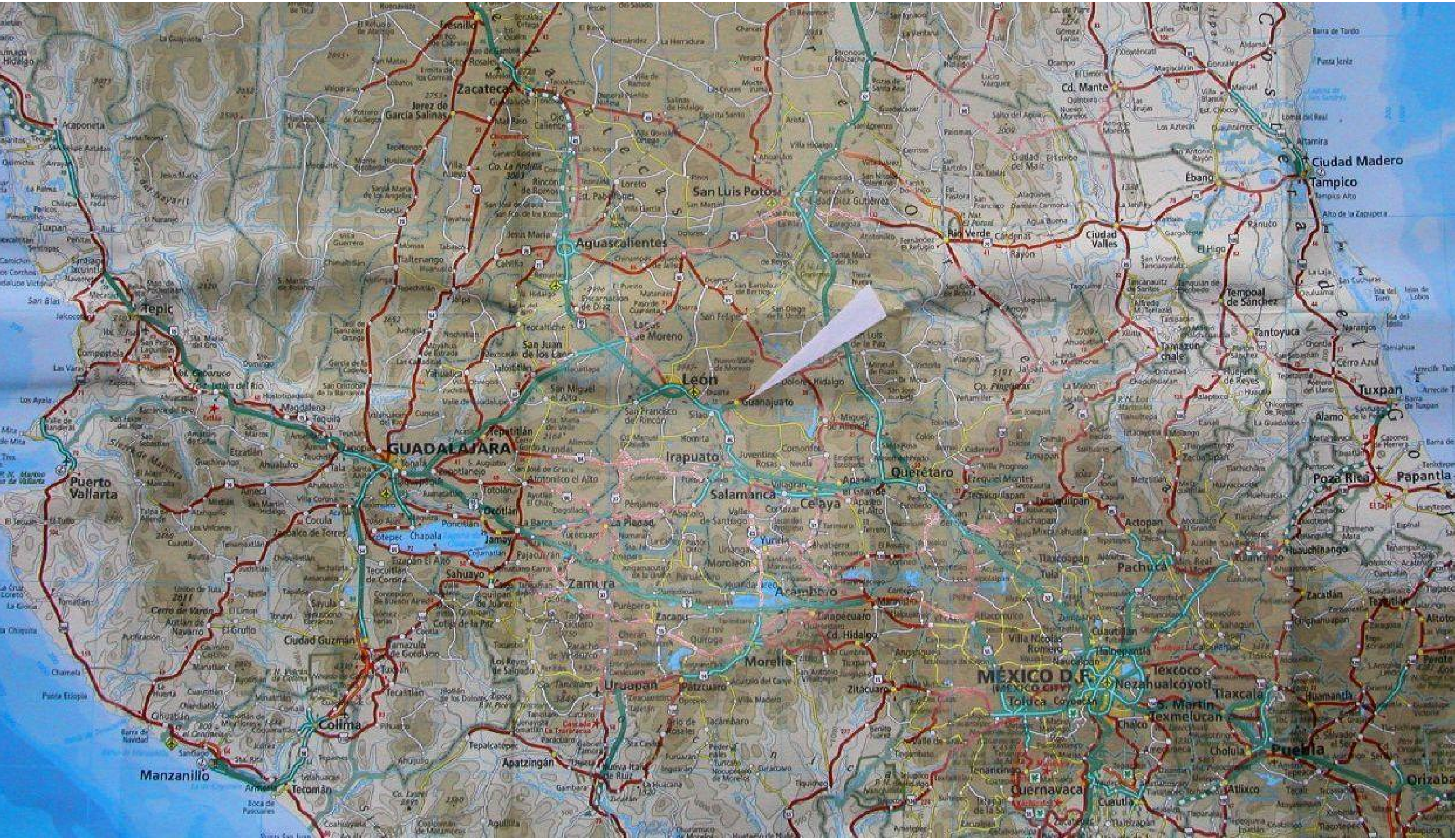
- Kinematics of BCM (Andernach et al.) and on
- Evolution of galaxies in CG (Plauchu et al.)

# Job vacancy: tenure track position in Mexico

## A view from our premises onto colonial Guanajuato

## visit us at http://www.astro.ugto.mx

# We are located at the geometric center of Mexico:




We seek: extragalactic astronomer/observational cosmologist

Contact me/us at heinz@astro.ugto.mx

# Variation of Abell cluster richness with z

| | $z=0$ | $z=0.05$ | $z=0.1$ | $z=0.15$ | $z=0.2$ | $z=0.25$ | $z=0.3$ | $z=0.35$ |
|---|---|---|---|---|---|---|---|---|
| | | | | number of clusters | | | | |
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| | | | | frequency per bin | | | | |
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| $R=2$ | 0.03 | 0.04 | 0.07 | 0.15 | 0.27 | 0.31 | 0.36 | 0 |
| $R=3$ | 0 | 0.01 | 0 | 0.02 | 0.06 | 0.11 | 0.08 | 0.5 |
| $R=4$ | 0 | 0 | 0 | 0 | 0.01 | 0.01 | 0 | 0 |
| | | | | expected increase for constant density | | | | |
| | | 26.00 | 3.77 | 2.22 | 1.77 | 1.56 | 1.44 | 1.36 |
| | | | | observed increase | | | | |
| $R=0$ | | 24.81 | 1.03 | 0.75 | 0.32 | 0.18 | 0.21 | 0.14 |
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| $R=3$ | | | 1.20 | 6.17 | 1.54 | 0.28 | 0.13 | 0.50 |
| $R=4$ | | | | | | 0.17 | | |

From z = .02 to .1 the frequency of poor ACO clusters with R=0 decreases only by factor of 1.3.

… while CG-associated R=0 ACO clusters decrease by factor of 6 passing from SCGs to PCGs.

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Increase in richness of the PCG-associated ACO-clusters at intermediate z cannot be explained by an incompleteness of the Abell/ACO sample.

# Variation of NSC abundance with redshift

- The phenomenon we observe for the CGs is consistent is with a genuine decrease of small-scale structures at higher redshift and, consequently, of an increase of structure masses at higher redshift.

| | $z=0$ | $z=0.05$ | $z=0.1$ | $z=0.15$ | $z=0.2$ | $z=0.25$ | $z=0.3$ | $z=0.35$ | $z=0.4$ | $z=0.45$ |
|---|---|---|---|---|---|---|---|---|---|---|
| number of clusters | | | | | | | | | | |
| $N<30$ | 245 | 692 | 1068 | 774 | 450 | 351 | 176 | 51 | 6 | 1 |
| 30-49.9 | 0 | 72 | 544 | 1232 | 987 | 535 | 238 | 71 | 18 | 3 |
| 50-69.9 | 0 | 18 | 72 | 179 | 150 | 61 | 22 | 11 | 4 | 4 |
| 70-99.9 | 0 | 35 | 18 | 23 | 16 | 10 | 2 | 0 | 0 | 0 |
| $N\geq 100$ | 0 | 3 | 6 | 12 | 7 | 4 | 1 | 0 | 1 | 2 |
| frequency per bin | | | | | | | | | | |
| $N<30$ | 1 | 0.88 | 0.63 | 0.35 | 0.28 | 0.37 | 0.40 | 0.38 | 0.21 | 0.10 |
| 30-49.9 | 0 | 0.09 | 0.32 | 0.55 | 0.61 | 0.56 | 0.54 | 0.53 | 0.62 | 0.30 |
| 50-69.9 | 0 | 0.02 | 0.04 | 0.08 | 0.09 | 0.06 | 0.05 | 0.08 | 0.14 | 0.40 |
| 70-99.9 | 0 | 0 | 0.01 | 0.01 | 0.01 | 0.01 | 0 | 0 | 0 | 0 |
| $N\geq 100$ | 0 | 0 | 0 | 0.01 | 0 | 0 | 0 | 0 | 0.03 | 0.02 |
| expected increase for constant density | | | | | | | | | | |
| | | 26.00 | 3.77 | 2.22 | 1.77 | 1.56 | 1.44 | 1.36 | 1.31 | 1.27 |
| observed increase | | | | | | | | | | |
| $N<30$ | | 2.82 | 1.54 | 0.72 | 0.58 | 0.78 | 0.50 | 0.29 | 0.12 | 0.17 |
| 30-49.9 | | | 7.56 | 2.26 | 0.80 | 0.54 | 0.44 | 0.30 | 0.25 | 0.17 |
| 50-69.9 | | | 4.00 | 2.49 | 0.84 | 0.41 | 0.36 | 0.50 | 0.36 | 1.00 |
| 70-99.9 | | | 6.00 | 1.28 | 0.70 | 0.63 | 0.20 | | | |
| $N\geq 100$ | | | 2.00 | 2.00 | 0.58 | 0.57 | 0.25 | | | 2.0 |