

Environmental quantification and H α characterisation of the most isolated galaxies in the local Universe

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- ▶ Role of the environment in the formation and evolution of galaxies
- ▶ Properties of the ISM in isolated galaxies, and its relation to luminosity, morphology, star formation, nuclear activity
- ▶ Reference sample with minimum influence from the environment

Analysis of the Interstellar Medium of Isolated GALaxies

(AMIGA project)

1. The Catalogue of Isolated Galaxies (CIG)

- ▶ Positions
- ▶ Redshifts and distances
- ▶ Morphologies
- ▶ Isolation

2. ISM multi-wavelength study

- ▶ H α
- ▶ Near & far infrared
- ▶ Radio-continuum
- ▶ Atomic gas
- ▶ Molecular gas

3. Public database

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The Catalogue of Isolated Galaxies (CIG)

Primary galaxies with angular major-axis diameter D_p are considered **isolated** if any neighbours with diameters D_i , $D_p/4 \leq D_i \leq 4D_p$ have an apparent angular separation R_{ip} , from the primary galaxy under consideration, greater than $20D_i$ [Karachentseva, 1973]:

$$R_{ip} \geq 20 \times D_i$$

$$\frac{1}{4} \times D_p \leq D_i \leq 4 \times D_p$$

1050 galaxies (about **3%** of all the galaxies in the CGCG)

[Zwicky et al., 1968]

Isolation definition



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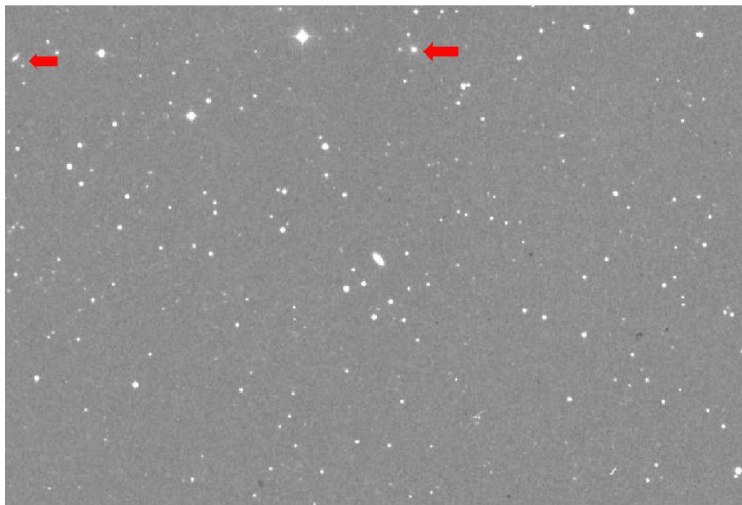
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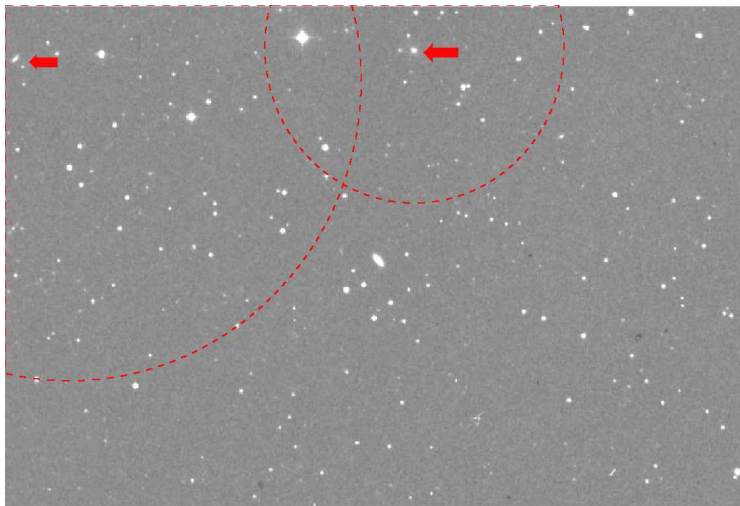
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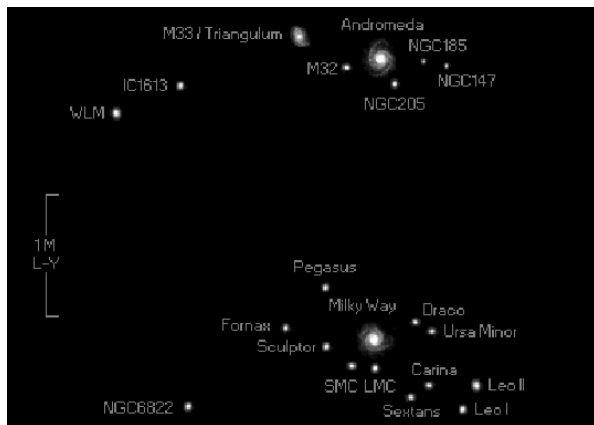
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Local group

- ▶ Milky Way: $D \approx 30$ kpc
- ▶ Andromeda: $D \approx 40$ kpc, dist. ≈ 725 kpc
- ▶ M33: $D \approx 16$ kpc, dist. ≈ 795 kpc
- ▶ Large Magellanic Cloud: $D \approx 9$ kpc, dist. ≈ 50 kpc



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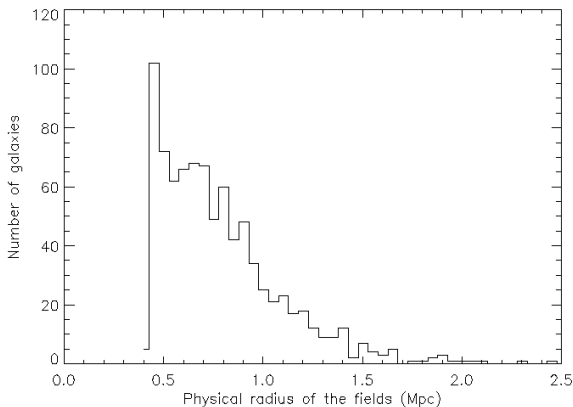
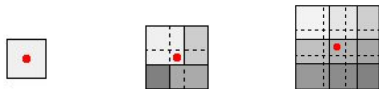
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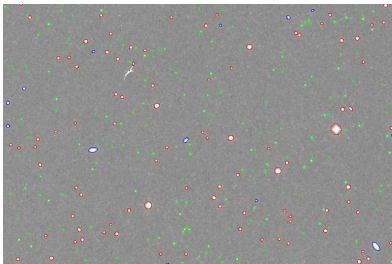
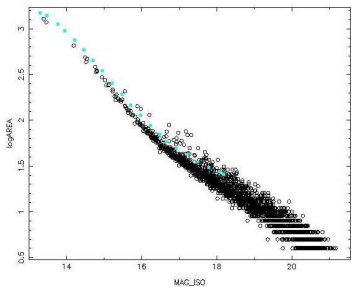
The AMIGA revision

- ▶ concerns 950 CIGs ($V > 1500 \text{ km s}^{-1}$)
- ▶ minimum physical radius of 0.5 Mpc (3×10^9 years)
- ▶ squared fields: 55' (767), 110' (134), 165' (49)



Isolation pipeline

- ▶ POSS-I digitised plates (1.7 arcsec/pixel)
- ▶ SExtractor for the detection [Bertin & Arnouts, 1996]
- ▶ LMORPHO for the star/galaxy separation [Odewahn, 1995]
- ▶ POSS-II digitised plates (1.0 arcsec/pixel)



54,000 neighbours around 950 CIGs

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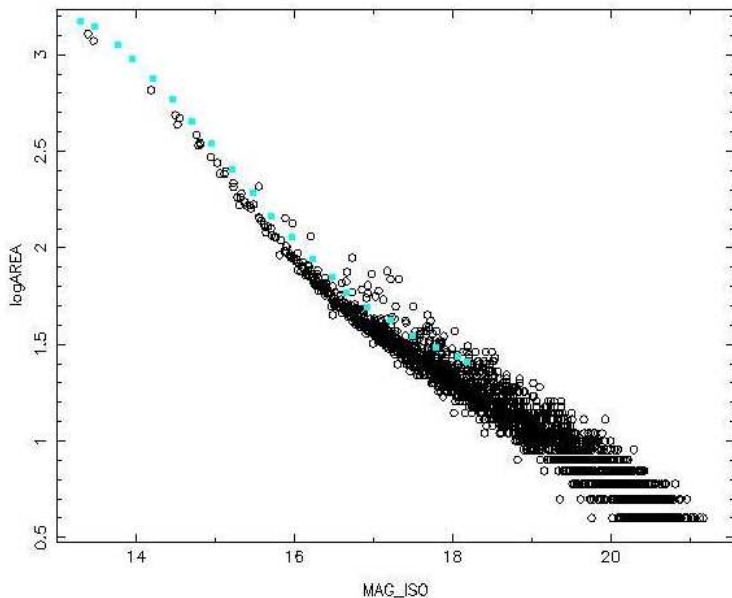
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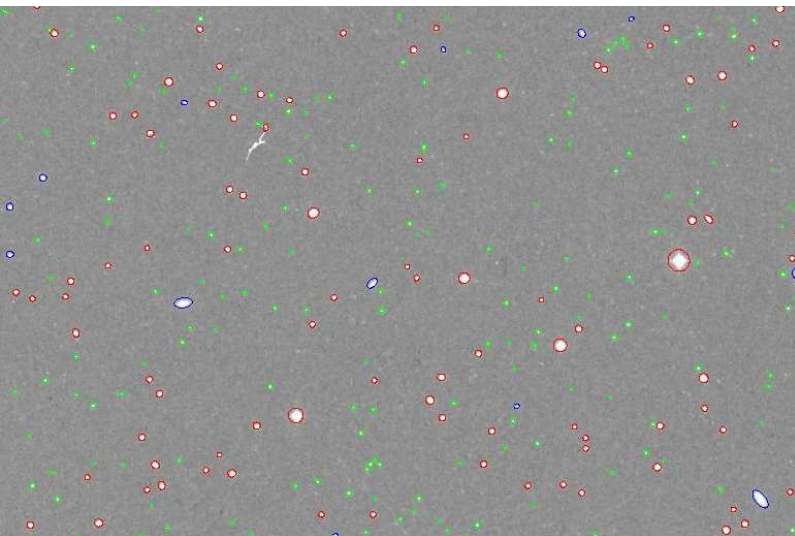
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1. Karachentseva's criterion
2. Pairs
3. k -density estimator (*similar size companions*) (Log)
4. Projected density within 0.5 Mpc
5. Projected density within 0.5 Mpc (*similar size companions*)
6. Tidal forces (Log)
7. Tidal forces (*similar size companions*) (Log)
8. Tidal forces within 0.5 Mpc (Log)
9. Tidal forces within 0.5 Mpc (*similar size companions*) (Log)

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Local density & projected density

Local density k^{th} nearest neighbour [Casertano & Hut, 1985]:

$$\eta_k = \frac{k - 1}{V(r_k)}$$

with $V(r_k) = 4\pi r_k^3/3$, where r_k is the distance to the k^{th} nearest neighbour

Projected density Number of companions projected within
0.5 Mpc

Tidal forces

$$F_{tidal} = \frac{M_c \times \Delta R}{R^3} = \frac{M_c \times D_p}{S^3}$$

$$F_{bind} = \frac{M_p}{D_p^2}$$

$$Q \equiv \frac{F_{tidal}}{F_{bind}} \propto \left(\frac{M_c}{M_p}\right) \left(\frac{D_p}{S}\right)^3 \propto \frac{(\sqrt{D_p D_c})^3}{S^3}$$

using the empirical relation [Rubin et al., 1982]:

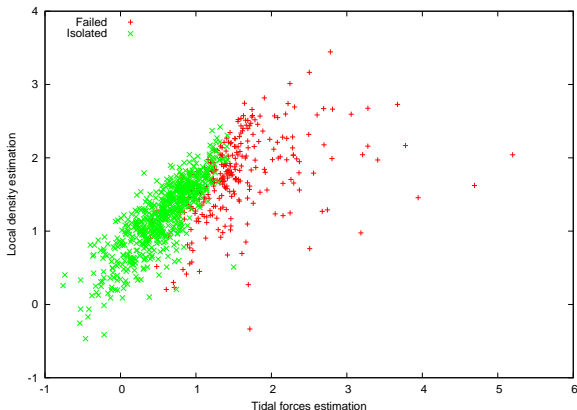
$$M \propto D^{\frac{3}{2}}$$

Hence, Q is a dimensionless estimation of the gravitational interaction strength [Dahari, 1984]

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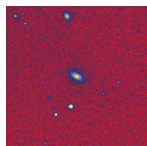
1. Karachentseva's criterion

- ▶ 67 fields covering $80 \times D_p$: 54 CIG galaxies isolated
- ▶ 284 CIG galaxies violating Karachentseva's isolation definition; 666 remaining isolated

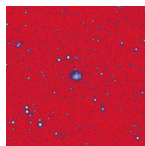
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2. Pair candidates

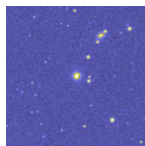
CIG galaxy with at least one companion (factor 2 in size with respect to D_p) within $5 \times D_p$:



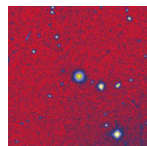
CIG 0019



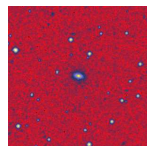
CIG 0036



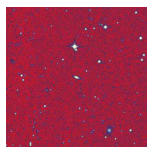
CIG 0074



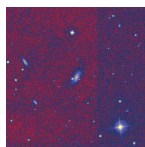
CIG 0178



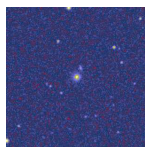
CIG 0233



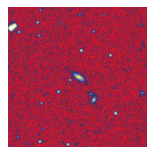
CIG 0315



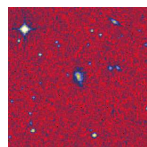
CIG 0488



CIG 0533

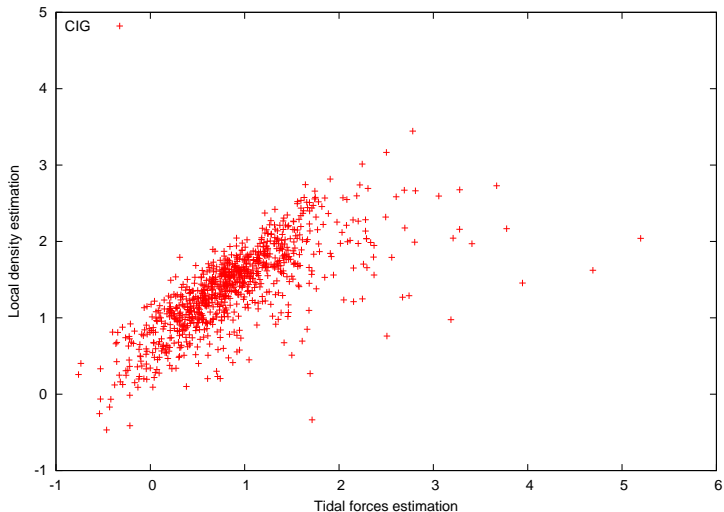


CIG 0683



CIG 0934

3. Complementarity between the isolation parameters



1. Karachentseva Triplets of Galaxies (KTG)

[Karachentseva et al. 1979]

2. Hickson Compact Groups (HCG)

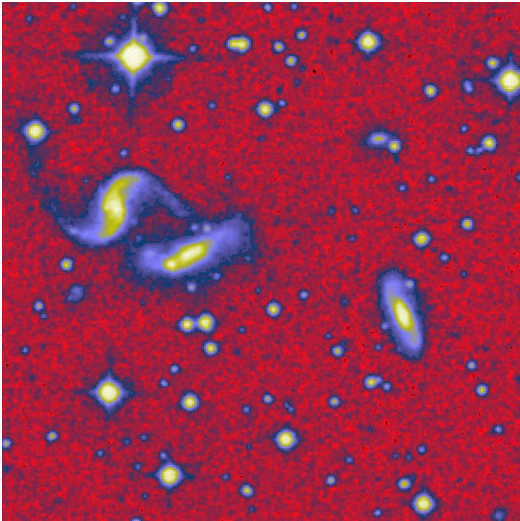
[Hickson 1982]

3. Abell Clusters (ACO)

[Abell 1958; Abell et al. 1989]

1. Karachentseva Triplets of Galaxies (KTG)

- ▶ 41 triplets selected
- ▶ primary galaxy = "A" galaxy



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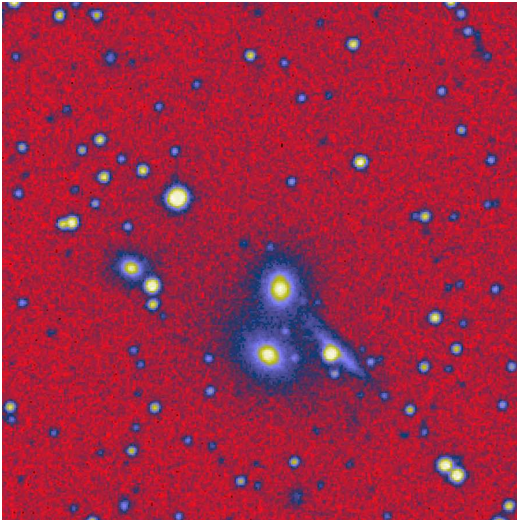
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2. Hickson Compact Groups (HCG)

- ▶ 34 groups selected
- ▶ primary galaxy = "A" galaxy



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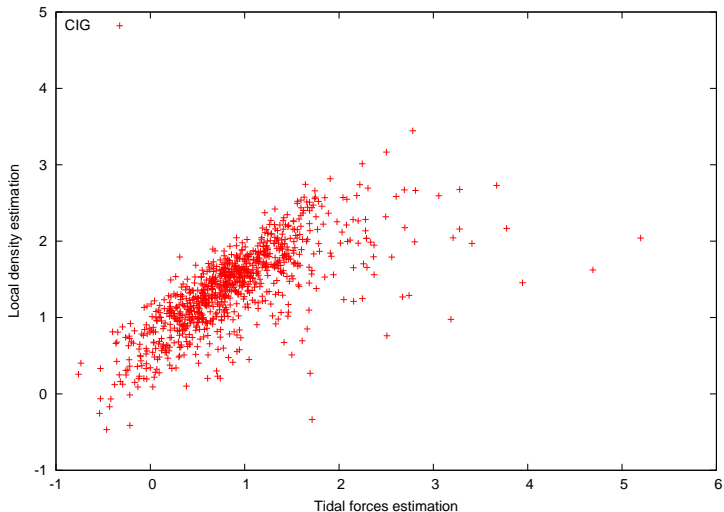
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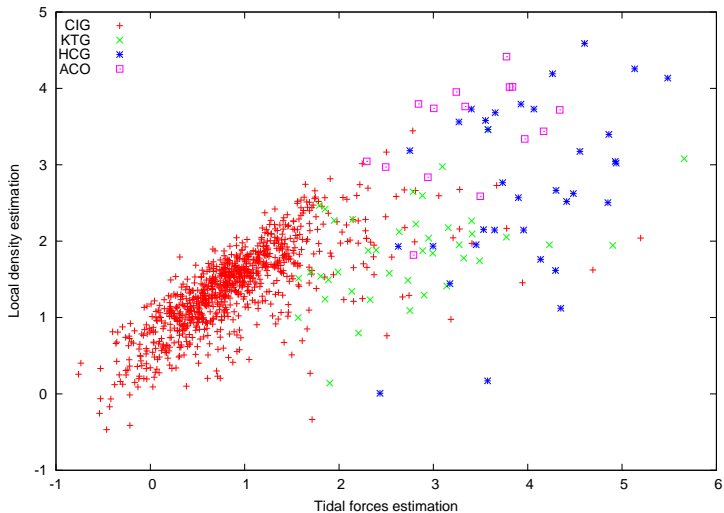
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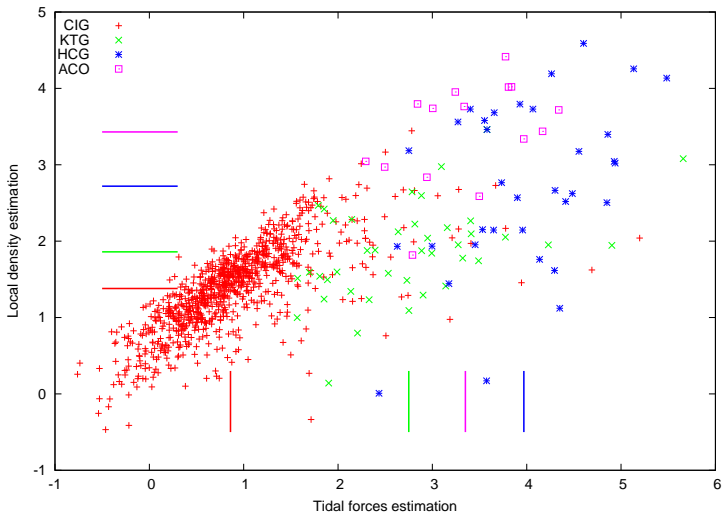
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Database or survey	Number of redshifts	Number of matched objects	Percentage of GALAXY
NED	8024	35317	99.97%
hyperLEDA	11608	25614	99.99%
SDSS	12166	12166	99.79%
CfA (velocity)	8864	9103	99.86%
2dF	3018	3018	-
UZC	1461	1488	-
UZC J2000	1445	1485	-
CfA2	866	866	100%
CfA1	106	106	100%
NOG2	67	67	-
NOG4	66	66	-
SSRS2	50	50	-
	16126 (29.86%)		GALAXY (99.90%)

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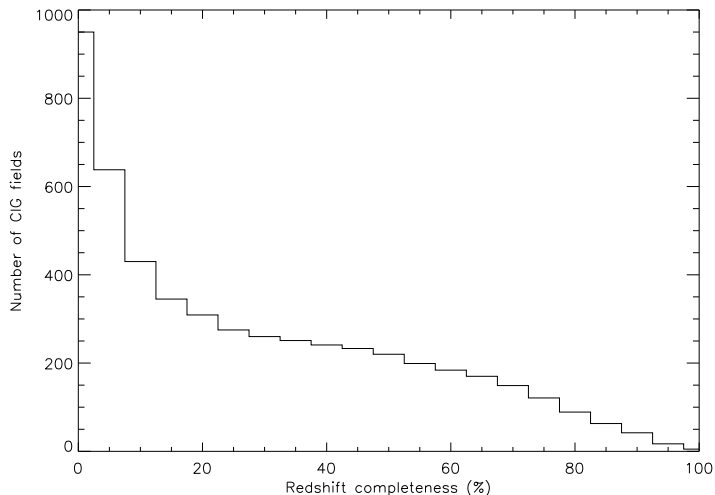
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Redshift Completeness

- ▶ completeness $\leq 20\%$: 641 fields
- ▶ completeness $\geq 80\%$: 89 fields



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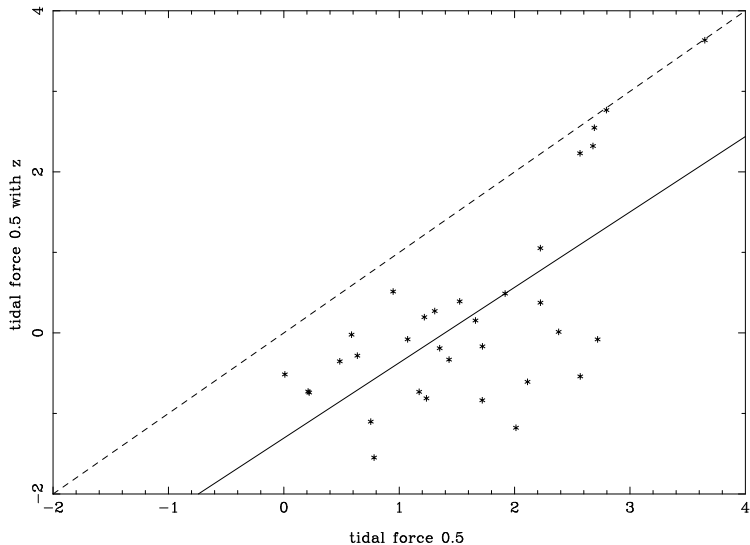
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Classification of the isolation

Tidal forces	Classification	Number of CIG
↑ 3	Interacting	26
 2	Poorly isolated	117
 1	Quite isolated	446
 0	Isolated	333
↓	Very isolated	28

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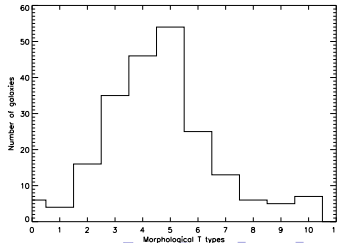
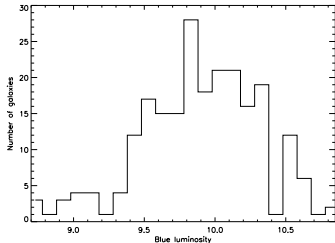
Definition of the H α sample

H α :

- ▶ young hot stars ($T > 10000K$): UV photons can ionise the circumstellar medium
- ▶ recent star formation history tracer: last 10-100 Myrs, $M_{star} > 20M_{sun}$

224 spiral CIG galaxies with observed recession velocity V :

$$1500kms^{-1} \leq V \leq 5000kms^{-1}$$



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CCD photometry:

1. $H\alpha$
 2. r Gunn
 3. standard stars
- } Complete for 200 galaxies

Telescopes:

1. Observatorio de Sierra Nevada (IAA) 1.50 m
2. Calar Alto Hispano-Alemán (MPI, IAA) 2.20 m
3. Estación de Observación de Calar Alto (OAN) 1.52 m
4. Jakobus Kapteyn Telescope (ING) 1.00 m
5. San Pedro Mártir (UNAM) 1.50 m

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The campaigns

Telescope	Date	Number of nights
OSN 1.5 m	03/31/2003 - 04/06/2003	7
	04/30/2003 - 05/03/2003	3
	08/25/2003 - 08/31/2003	7
	11/24/2003 - 11/30/2003	7
	06/18/2004 - 06/27/2004	10
	08/16/2004 - 08/20/2004	5
	09/13/2004 - 09/18/2004	6
	12/05/2004 - 12/12/2004	8
	01/10/2005 - 01/16/2005	7
	03/10/2005 - 03/16/2005	7
	04/11/2005 - 04/15/2005	5
	05/23/2005 - 05/23/2005	1
	06/06/2005 - 06/07/2005	2
	10/01/2005 - 10/01/2005	1
11/13/2005 - 11/13/2005	1	
CAHA 2.2 m	01/01/2003 - 01/06/2003	6
	08/01/2003 - 08/06/2003	6
	09/01/2003 - 09/01/2003	1
	09/16/2003 - 09/16/2003	1
	02/21/2004 - 02/26/2004	6
	04/20/2004 - 04/25/2004	6
EOCA 1.52 m	10/20/2003 - 10/25/2003	6
	02/22/2004 - 02/24/2004	3
	05/19/2004 - 05/21/2004	3
JKT 1.0 m	07/22/2003 - 07/31/2003	10
SPM 1.5 m	05/01/2003 - 05/04/2003	4

- ▶ subtraction of the super-bias
- ▶ first rejection of cosmic rays
- ▶ division by the super-flat
- ▶ estimation and subtraction of the sky background
- ▶ division by the exposure time
- ▶ centering of all the images for any given galaxy
- ▶ equalizing the PSF of all the images for any given galaxy
- ▶ final combination in each filter
- ▶ scaling the continuum to the H α image and subtraction

IRAF - Image Reduction and Analysis Facility

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- ▶ subtraction of the super-bias
- ▶ first rejection of cosmic rays
- ▶ division by the super-flat
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- ▶ division by the exposure time
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- ▶ equalizing the PSF of all the images for any given galaxy
- ▶ final combination in each filter
- ▶ **scaling the continuum to the H α image and subtraction**

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H α - continuum images

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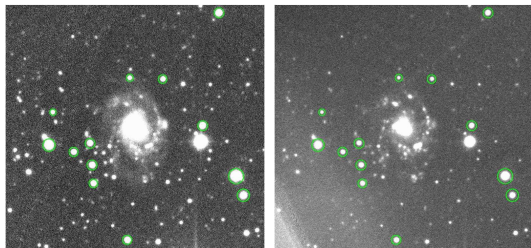
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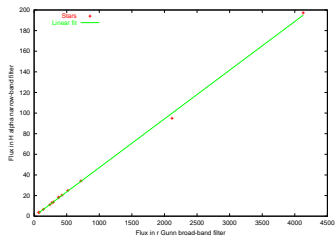
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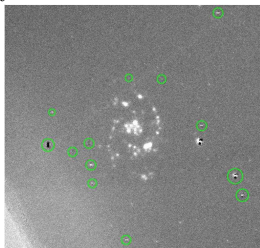


r Gunn

H α



Scale factor



H α - continuum

Sufficient spatial resolution In the case of our observations, this translates into galaxies having major axis greater or equal to **1 arcmin**;

Low-inclination In order to obtain a sufficiently accurate deprojection, the inclination has to be minor or equal to **50°**.

45 galaxies

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- ▶ The surface **density** is decomposed as:

$$\mu(r, \phi) = \mu_0(r) + \sum_m a_m(r) \cos(m\phi - \phi_m(r))$$

where the normalised strength of the Fourier component m is $A_m(r) = a_m/\mu_0(r)$.

- ▶ The **potential** is decomposed as:

$$\Phi(r, \theta) = \Phi_0(r) + \sum_m \Phi_m(r) \cos(m\theta - \phi_m)$$

where the strength of the m -Fourier component is $Q_m(r) = m\Phi_m/r|F_0(r)|$, and its global strength over the disk: $\max_r (Q_m(r))$.

- ▶ The maximal **torque** at a given radius is defined by:

$$Q_T(R) = \frac{F_T^{max}(R)}{F_0(R)} = \frac{\frac{1}{R} \left(\frac{\partial \Phi(R, \theta)}{\partial \theta} \right)_{max}}{\frac{d\Phi_0(R)}{dR}}$$

where $F_T^{max}(R)$ represents the maximum amplitude of the tangential force at radius R , and $F_0(R)$ is the mean axisymmetric radial force inferred from the $m=0$ component of the gravitational potential.

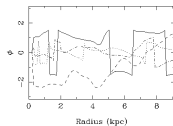
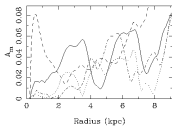
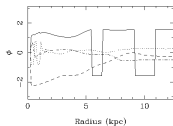
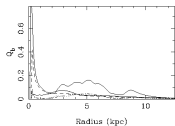
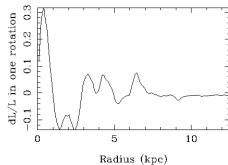
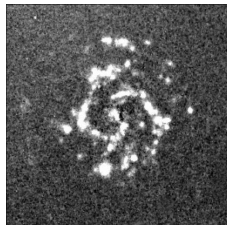
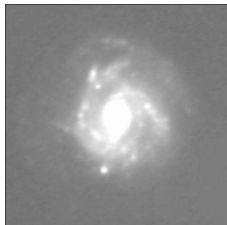
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Bar strengths

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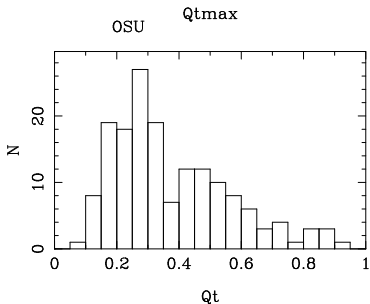
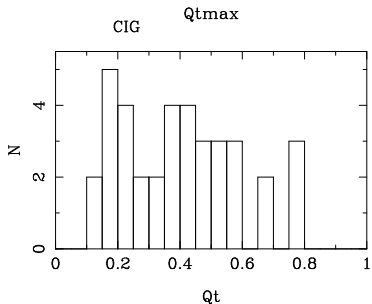
Observations

Data reduction

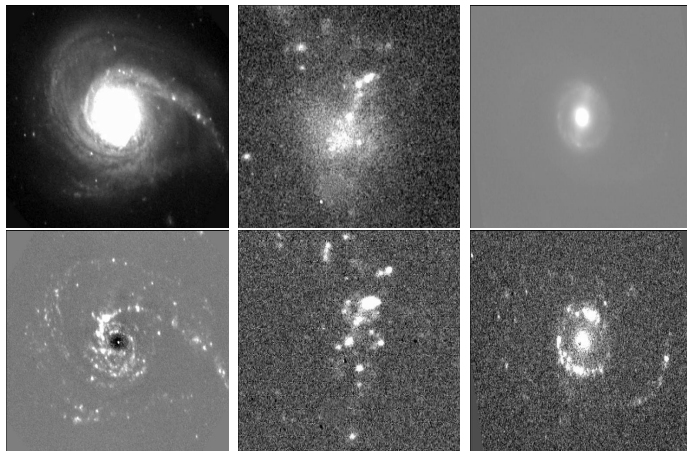
H α subsample

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Tidal forces > 3 : Interacting galaxies



CIG 0080
(3.974)

CIG 0085
(3.891)

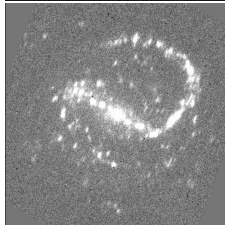
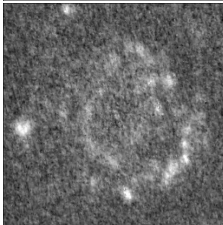
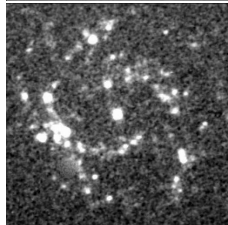
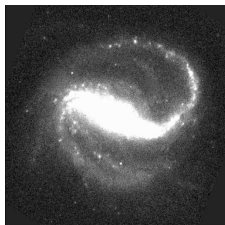
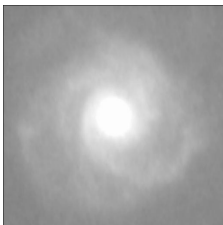
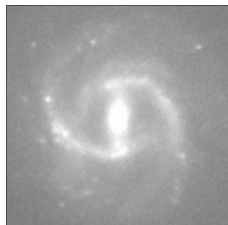
CIG 1001
(3.213)

Main Groups (E, F, G)

CIG 0053

CIG 0084

CIG 1004



group **E**
(19 galaxies)

group **F**
(9 galaxies)

group **G**
(8 galaxies)

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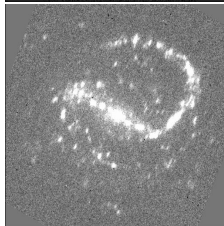
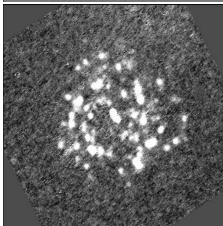
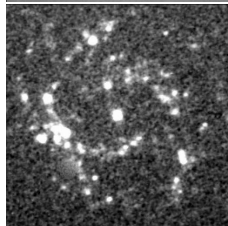
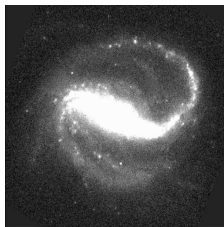
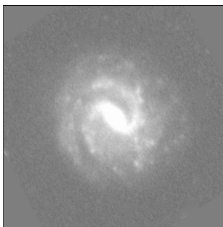
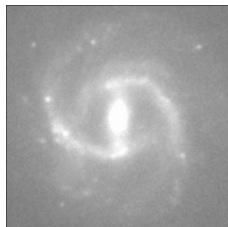
Resumen

Evolution of star formation in bars

CIG 0053

CIG 0512

CIG 1004



group **E**
(19 galaxies)
63%

group **EG**
(3 galaxies)
10%

group **G**
(8 galaxies)
27%

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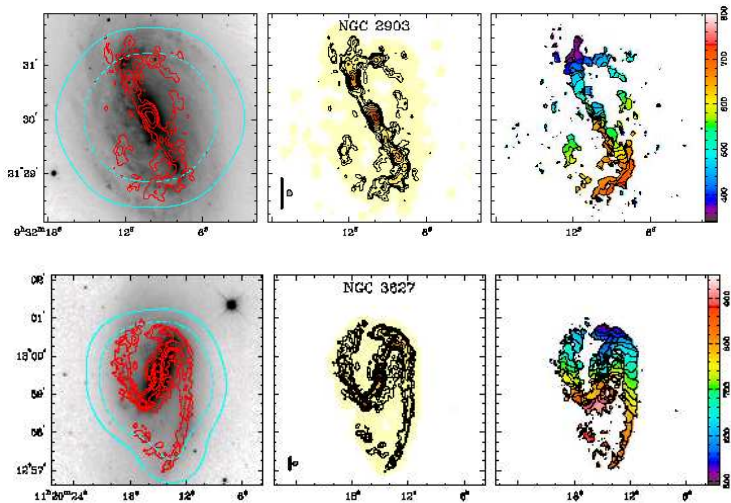
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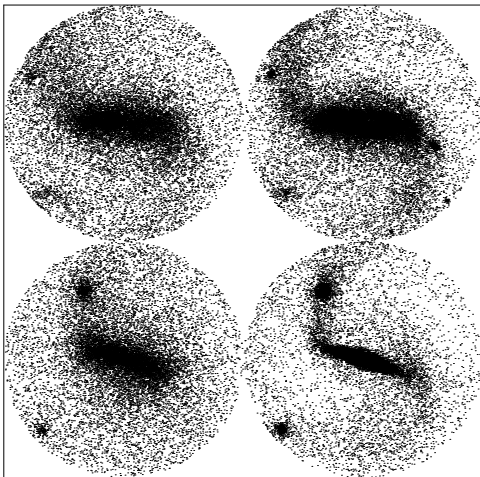
Numerical simulations: gaseous component

PhD Thesis

Dec. 20th, 2005

Stars

Gas 0.3Gyr



Stars

Gas 0.7Gyr

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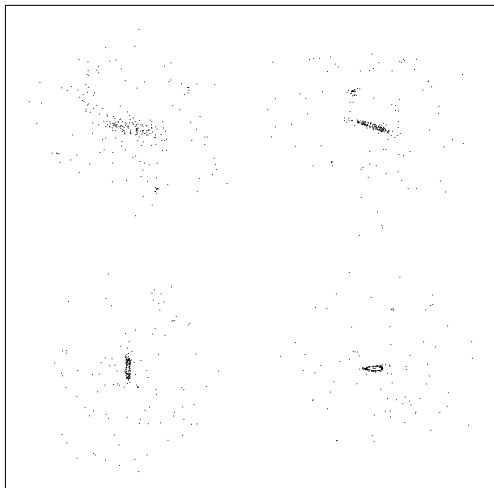
Numerical simulations: stellar component

PhD Thesis

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Ha 0.3Gyr

Ha 0.7Gyr



Ha 1.1Gyr

Ha 1.5Gyr

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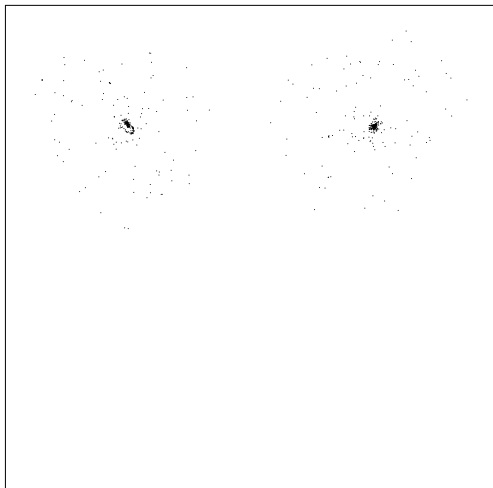
Numerical simulations: stellar component

PhD Thesis

Dec. 20th, 2005

Ha 1.9Gyr

Ha 2.4Gyr



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- Isolation
- ▶ Computer processing: to *detect* and *classify* sources around 950 CIG
 - ▶ Isolation degrees: continuous *isolation degrees* consistent for the whole sample and complementary
 - ▶ Comparison samples: KTG, HCG, ACO
 - ▶ Redshifts: verification of the type and 3-dimensional picture of the environment

- H α
- ▶ Observation of 200 galaxies
 - ▶ H α emission in bars and along the spiral arms
 - ▶ Torques between H α and bulk optical matter
 - ▶ Schmidt law insufficient

- ▶ Reduction of the whole sample to derive the local SFR and $H\alpha$ OLF of isolated galaxies
- ▶ CO maps of some particular galaxies
- ▶ Numerical simulations
- ▶ Comparison of the ISM properties of the AMIGA galaxies with galaxies in denser environments

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Resumen

- Aislamiento:**
- ▶ 950 galaxias del Catálogo de Galaxias Aisladas
 - ▶ Grado de aislamiento de esta muestra: parámetros complementarios
 - ▶ Muestras de comparación: entornos más densos
 - ▶ Dimensión radial
- Formación de estrellas:**
- ▶ Observaciones de 200 galaxias
 - ▶ Emisión H α en las barras y brazos espirales
 - ▶ Torques entre la emisión H α y el potencial
 - ▶ Ley de Schmidt es insuficiente