Isolated Galaxies
History of Research and Ideas Over the Past 40 Years

Jack Sulentic
Instituto de Astrofisica de Andalucia-CSIC (Spain)

1. Isolated Galaxies

DEFINITIONS: There are two kinds of "isolation":

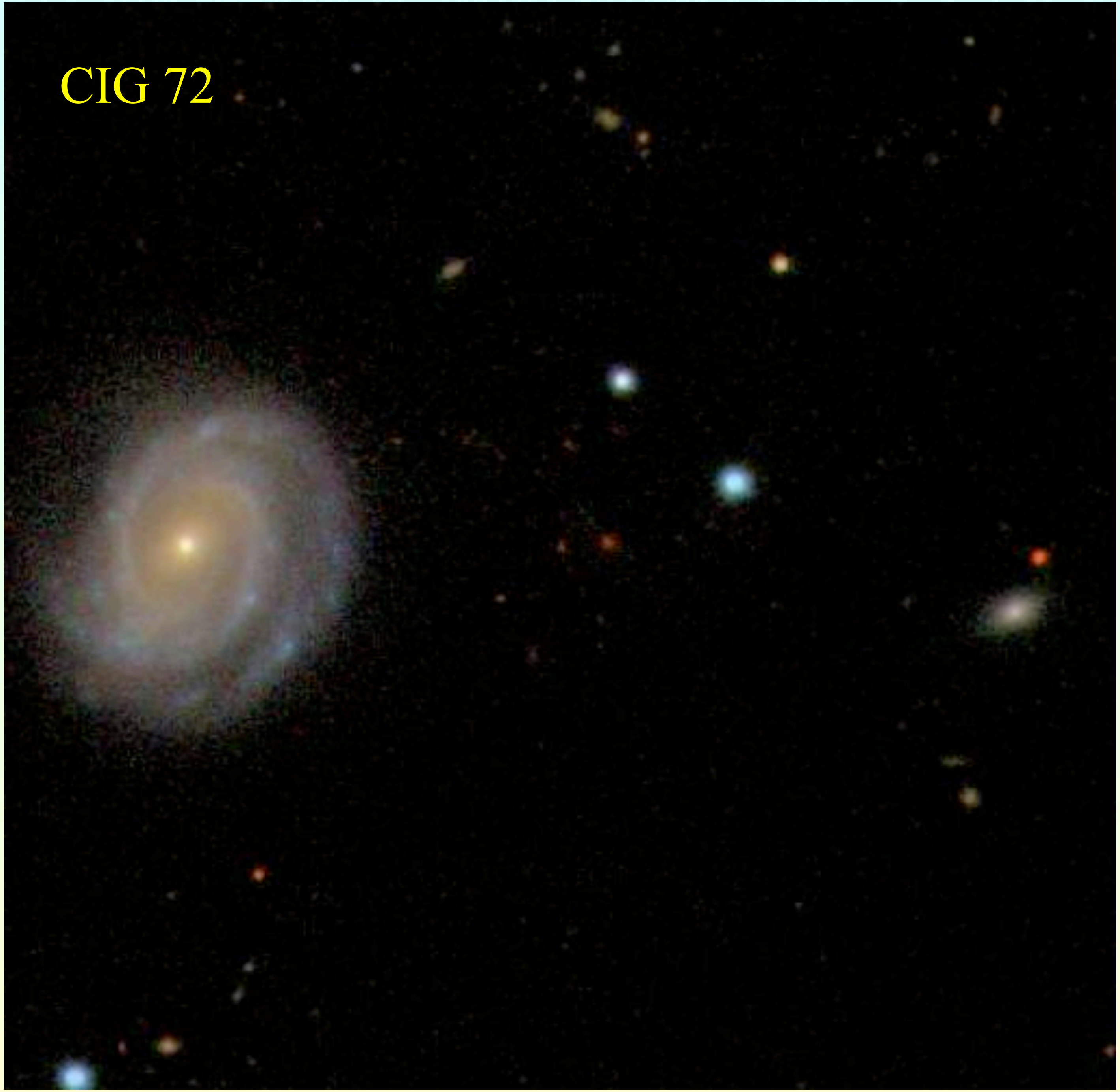
1) low environmental density (e.g. Voids and periphery of superclusters)

Important for early types—morphology-density relation

mergers and harassments

2) close companions (e.g. isolated pairs/triplets/CG's)

Important for late types—secular evolution, starbursts, AGN


CIG 72

1. Isolated Galaxies

Q? Why is the number of isolated pairs almost as large as the number of isolated singlets?

It tells us that 1 and 2 are not related.

Surely it favors top-down galaxy formation?

1. Isolated Galaxies

Lesson 1: Since ~1970

Algorithms cannot select well isolated galaxy (singlets/pairs/triplets/CGs) populations.

Two reasons:

1) close companions are often not listed separately in source catalogs
2) galaxies near flux limit of the source catalog employed will suffer “tip of the iceberg” effect.

Visual verification is required for robot selected samples.

That is why CIG and CPG remain relevant and useful.

1. Isolated Galaxies

Modern era begins with CIG (Karachentseva 1973)

SIZE: 800 – 1150 galaxies (depending on how you define “isolation”)

ISOLATION: typical $t_C \sim 3$ Gyr (see Verley)

COMPLEMENTARITY: matches well isolated pair (CPG) and triplet (CTG) catalogs (Karachentsev 1972, Karachentseva et al. 1979)

MORPHOLOGY: large enough to allow exploration of diversity (L, t)

DEPTH: 10000-15000 km/s

COMPLETENESS: V/V_m suggests 80-90% complete to B=15.0

Is it a "field" or simply the low density tail of the two point CF?

Einasto 1990 cluster analysis – no field?

A typical galaxy of **D = 25 kpc** has not been visited by a similar mass perturber in the past **3 Gyr** (assuming a typical field velocity of 150 km s^{-1}).

2. Radio Line 21 cm

Q: HI haloes larger? Smaller?
Q: HI content larger? Smaller?

Haynes & Giovanelli 1980, 1983ab, 1984 (using CIG)

1) redshift distribution not homogeneous but instead reflects major superstructure components within 15000 km/s

JS2) or a superstructure outlier component plus a homogeneous field component?

JS3) bimodal detection properties for "elliptical" subsample.

JS4) Types 5-7 (Sb-Sc) show very similar mean HI parameters??

3. Birth of Environmental Awareness

RADIO CONTINUUM

Sulentic 1976, Stocke 1978, Hummel 1980 – radio continuum stronger in interacting galaxies

OPTICAL COLORS

Larson & Tinsley 1978 – interacting galaxies are bluer than normal ones

RADIO LINE CO/H_2 and IR

Young et al. 1986

M_{H2} / L_B same for isolated and interacting

L_{IR} / L_B much stronger in interacting galaxies

L_{FIR} / L_{CO} also stronger in interacting galaxies (Solomon & Sage 1988)

for FIR see also: Cutri & McAlary 1985, Joseph & Wright 1985, Kennicutt et al. 1987, Xu & Sulentic 1991

3. Birth of Environmental Awareness

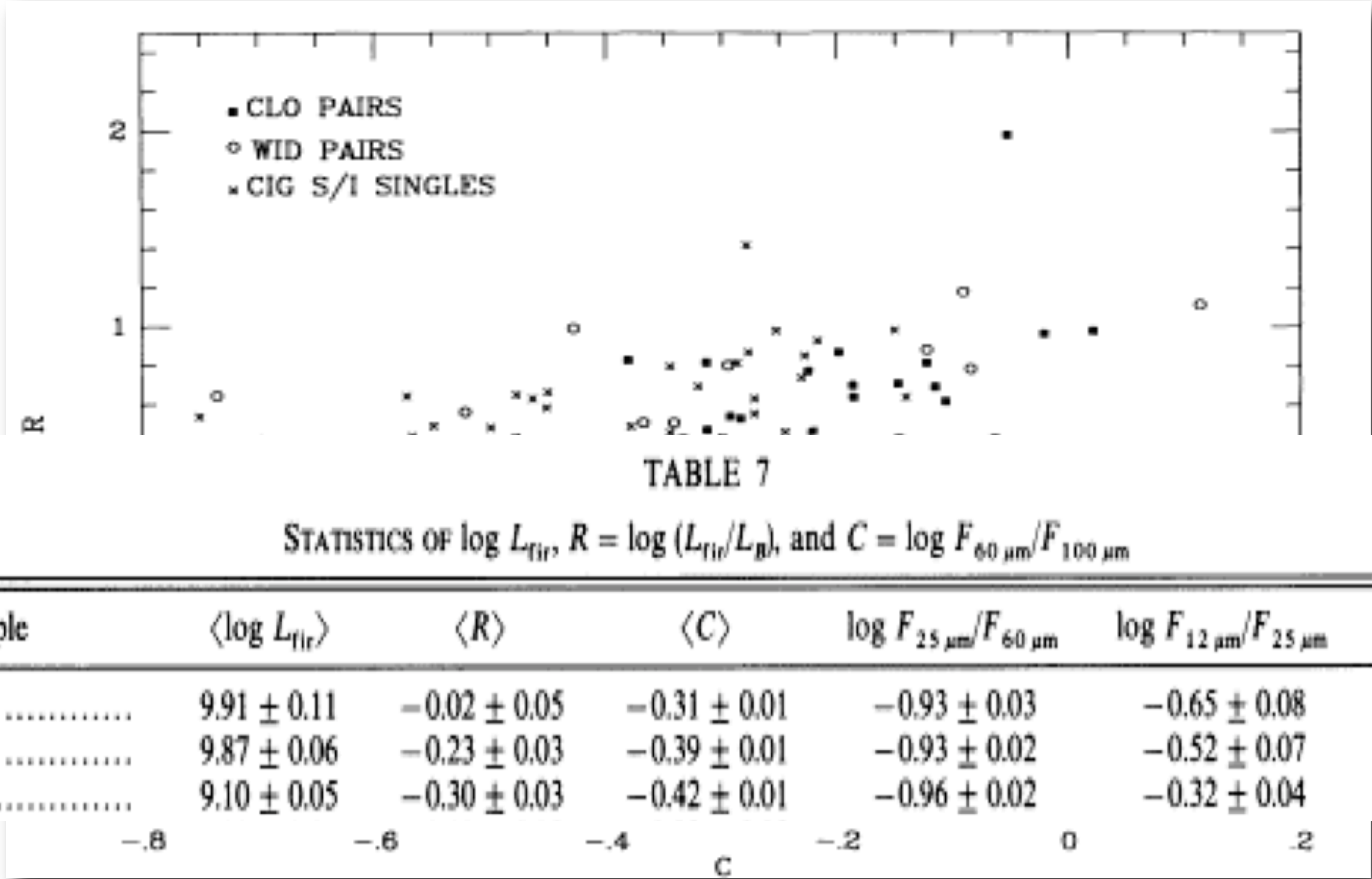


TABLE 7

STATISTICS OF $\log L_{\rm fir}$, $R = \log (L_{\rm fir}/L_B)$, and $C = \log F_{60\,\mu m}/F_{100\,\mu m}$

Sample	$\langle \log L_{\rm fir} \rangle$	$\langle R \rangle$	$\langle C \rangle$	$\log F_{25\,\mu m}/F_{60\,\mu m}$	$\log F_{12\,\mu m}/F_{25\,\mu m}$	$R_{w/c}$	$b \times 10^4$
CLO SS pairs	9.91 ± 0.11	−0.02 ± 0.05	−0.31 ± 0.01	−0.93 ± 0.03	−0.65 ± 0.08	0.72	4.0
WID SS pairs	9.87 ± 0.06	−0.23 ± 0.03	−0.39 ± 0.01	−0.93 ± 0.02	−0.52 ± 0.07	0.46	1.9
CIG S/Irr	9.10 ± 0.05	−0.30 ± 0.03	−0.42 ± 0.01	−0.96 ± 0.02	−0.32 ± 0.04	0.36	1.3

4. Other Isolated Studies

ISOLATED STARBURST GALAXIES? (e.g. NGC253?)

Triggered by infall of intergalactic clouds (Sofue & Wakamatsu 1991)

ISOLATED AGN?

Excess of companions, no excess, maybe excess, excess for Sy2 but not Sy1… Excess surface density or one-on-one?

Dahari 1984, 1985, Xanthopoulos & de Robertis 1991, Laurikainen et al. 1994, de Robertis et al. 1998, Rafanelli et al. 1995, Dultzin-Hacyan et al. 1999 (see Sabater)

MORE FINE STRUCTURE IN ISOLATED EARLY TYPES? (Reduzzi et al. 1996)

HI PROFILES OF ISOLATED GALAXIES – LESS ASYMMETRIC? (Haynes et al. 1998) (see Espada)

SAM vs M_HI (Zasov & Sulentic 1994)

OLF AROUND ISOLATED SPIRALS (Morgan et al. 1998)

4.Comparing Isolated and Non-Isolated

Spectroscopy and optical + IR photometry

Marquez & Moles 1996,1999;

Marquez et al. 1999, 2000, 2001, 2002ab, 2003, 2004ab

→ Small (22) to moderate (203) samples of spiral galaxies (cz ≤ 5000km/s)

4.Comparing Isolated and Non-Isolated

- later(Sc) types, symmetric morphologies, bluer, smaller?, less luminous?
- tighter Kormendy and Fisher-Tully relations
- narrower range of disk scale length and effective surface brightness
- disks bluer and more similar color than bulges?
- tight correlation G and B/D? (12 galaxies)
- flatter rotation curves

5. **AMIGA** project (**A**nalysis of the interstellar **M**edium of **I**solated **GA**laxies)

- Revision of CIG:
  - Positions (Leon & Verdes-Montenegro A&A 2003)
  - Optical characterization (Verdes-Montenegro et al. A&A 2005)
  - Morphological revision + OLF/types (Sulentic et al. A&A 2006)
  - Degree of isolation (Verley PhD; Verley et al 2007, A&A 470, 505; Verley et al 2007 A&A 472, 121)
- Multi-wavelength study:
  - FIR properties, IRAS data, N=1000 (Lisenfeld et al. 2007, A&A 462 507)
  - Radio-continuum emission, NVSS FIRST (Leon et al 2008, A&A 485)
  - Radio-FIR for radio-AGNs selection (Sabater et al 2008, A&A 486, 73)
  - SDSS spectra for optical AGN
  - Atomic gas content
  - CO(1-0) (N = 200) (Esp

See Verley, Sabater, Espada talks

(Espada PhD 2006)

5.1 AMIGA project: Velocity distribution

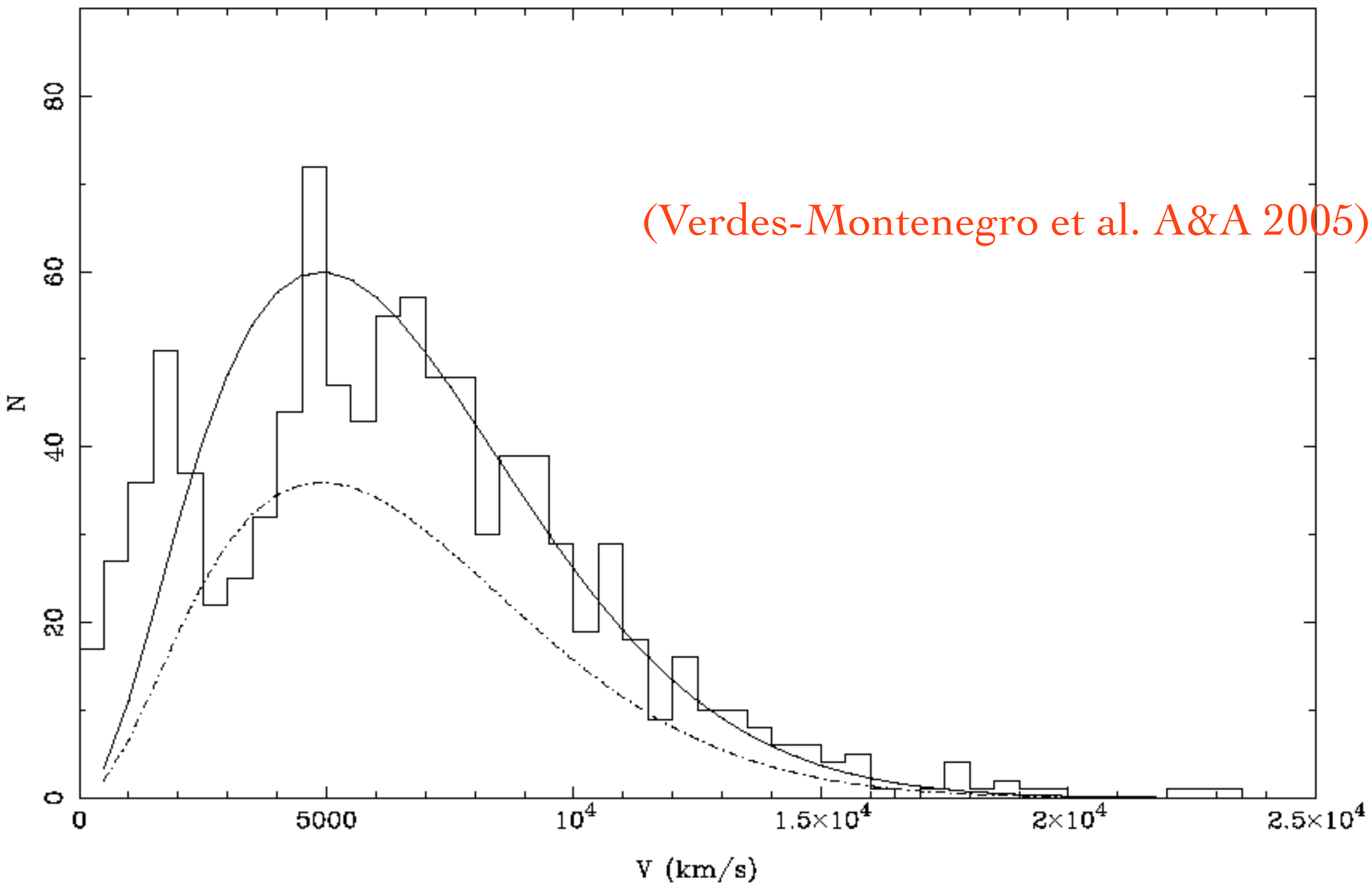
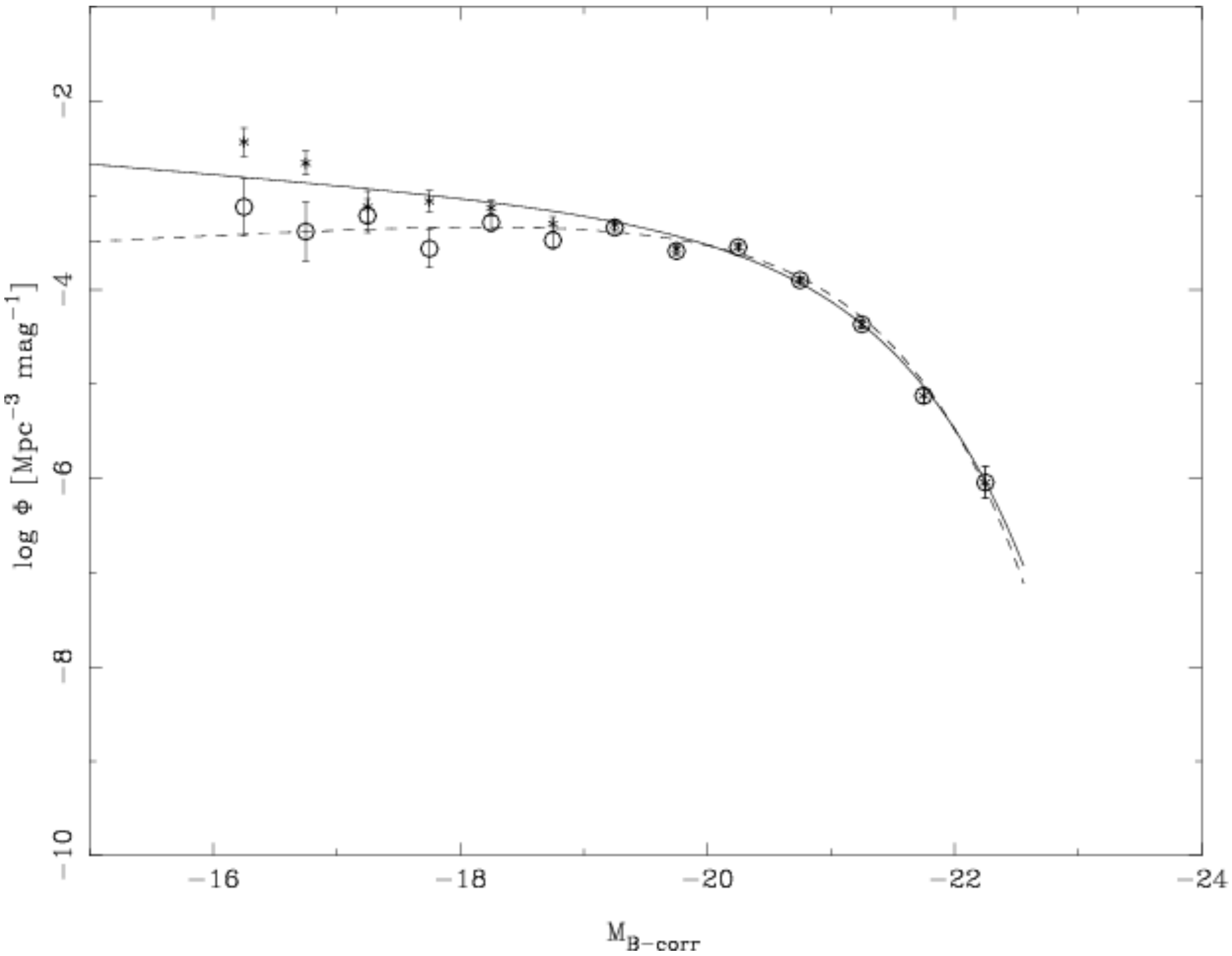


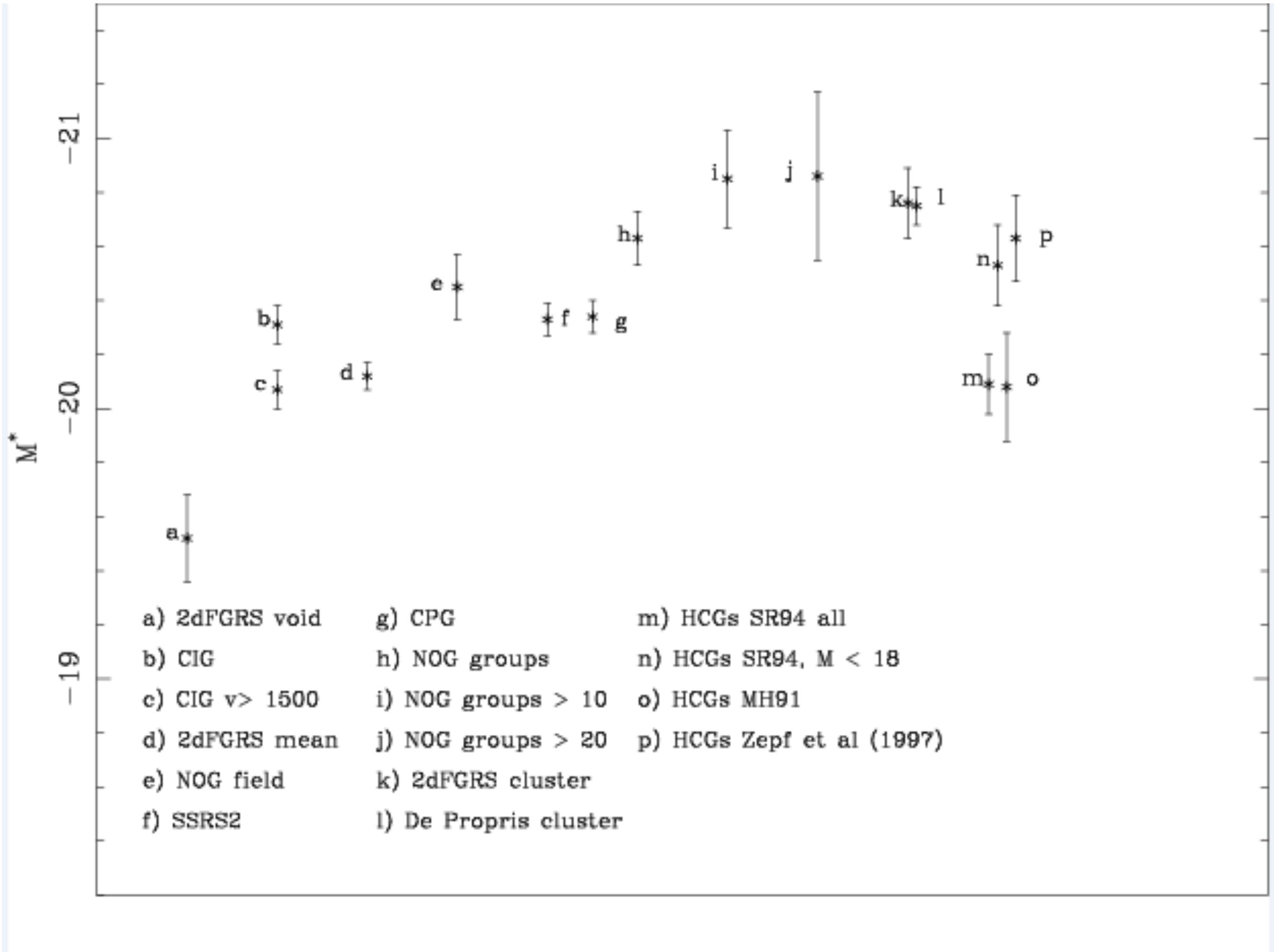
Fig. 3. Histogram of the optical heliocentric velocities of the 956 CIG galaxies with redshift data. Only CIG 402 is out of the plot, with V = 40658 km s^{-1}. The solid line corresponds to a homogeneous redshift distribution of the same sample size, velocity distribution and Schechter function. The dashed line has been obtained by scaling down the previous distribution by a factor of 0.6.

5.2 AMIGA project: Optical luminosity function



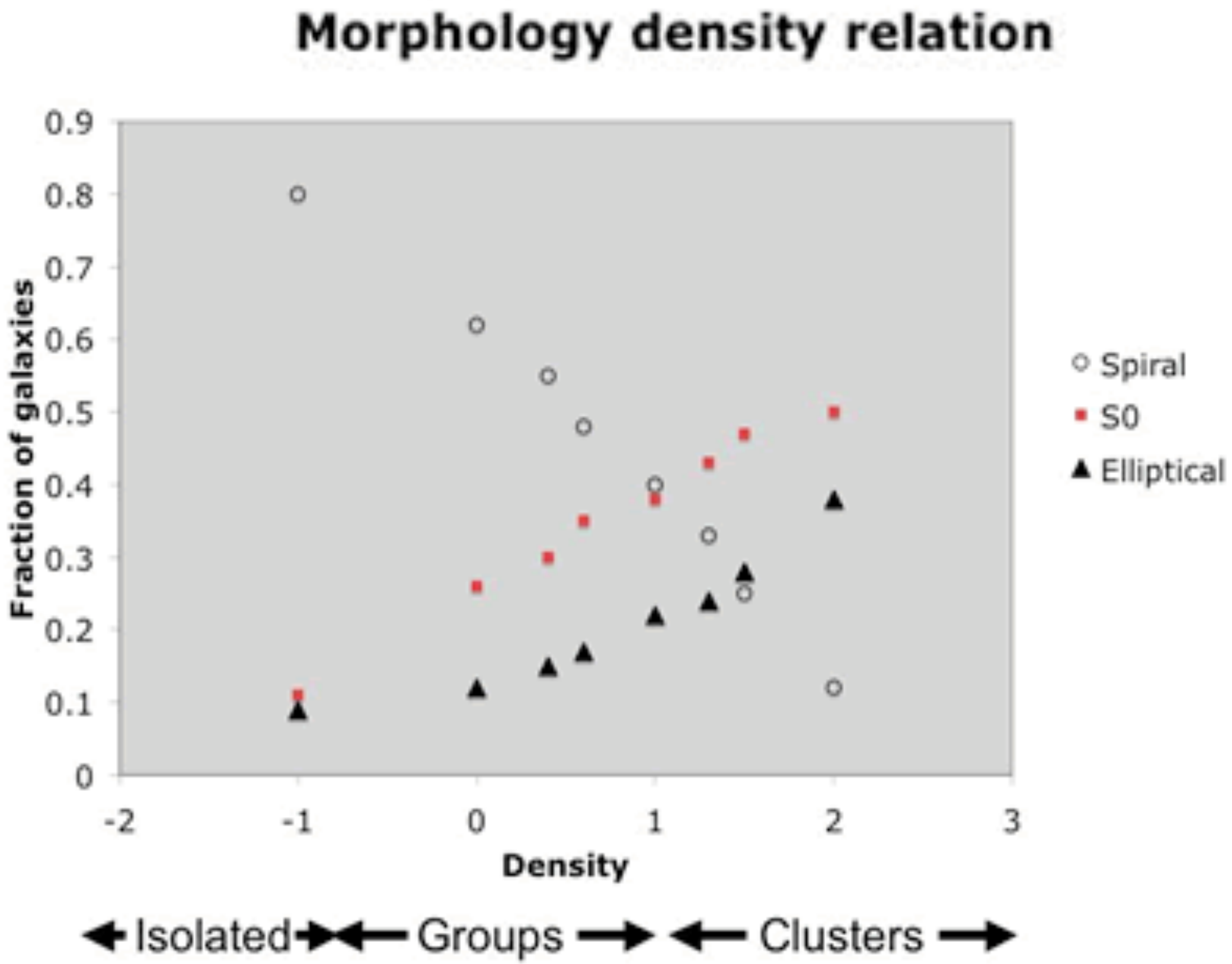
(Verdes-Montenegro et al. A&A 2005)

5.2 AMIGA project: Optical luminosity function



(Verdes-Montenegro et al. A&A 2005)

5.3 **AMIGA** project: Morphological type



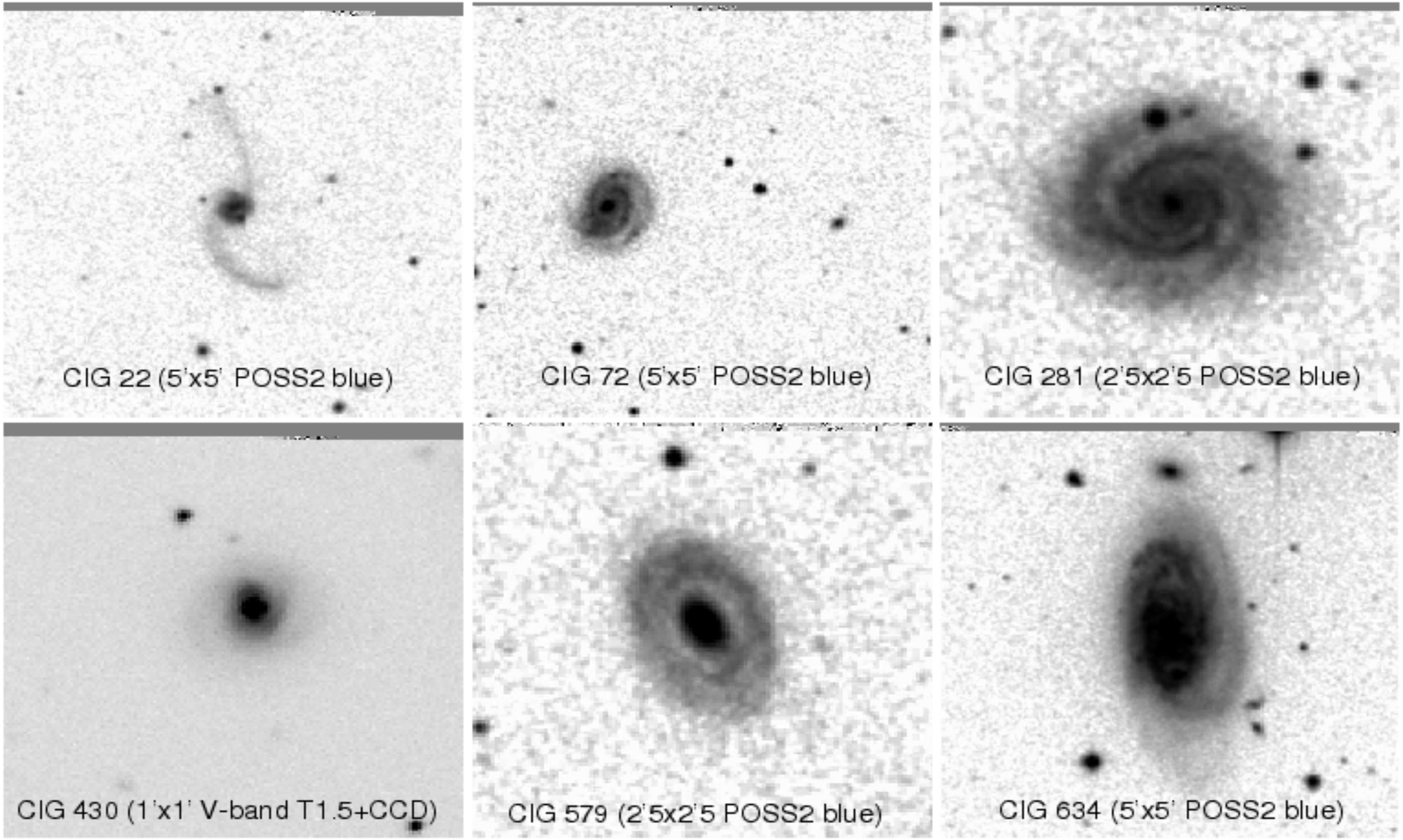
(http://astronomy.swin.edu.au)

5.3 AMIGA project: Morphological type

Type	T	n	$n/1018$	I/A=?	n_{SDSS}	$n_{\mathrm{SDSS}}/215$
I/A		32	—	0		
E	−5	58	0.057	1	7	0.032
E/S0	−3	14	0.014	0	4	0.019
S0	−2	67	0.066	3	17	0.079
S0/a	0	19	0.019	2	7	0.033
Sa	1	13	0.013	2	3	0.014
Sab	2	52	0.051	8	11	0.051
Sb	3	159	0.156	20	25	0.116
Sbc	4	200	0.196	40	33	0.153
Sc	5	278	0.273	68	69	0.321
Scd	6	61	0.060	7	15	0.070
Sd	7	41	0.040	7	13	0.060
Sdm	8	15	0.015	0	7	0.033
Sm	9	15	0.015	1	3	0.014
Im	10	26	0.026	2	7	0.033
E–S0		139	0.137	4	28	0.130
Sa–Sd		804	0.790	152	169	0.786
Sb–Sc		637	0.626	128	127	0.591

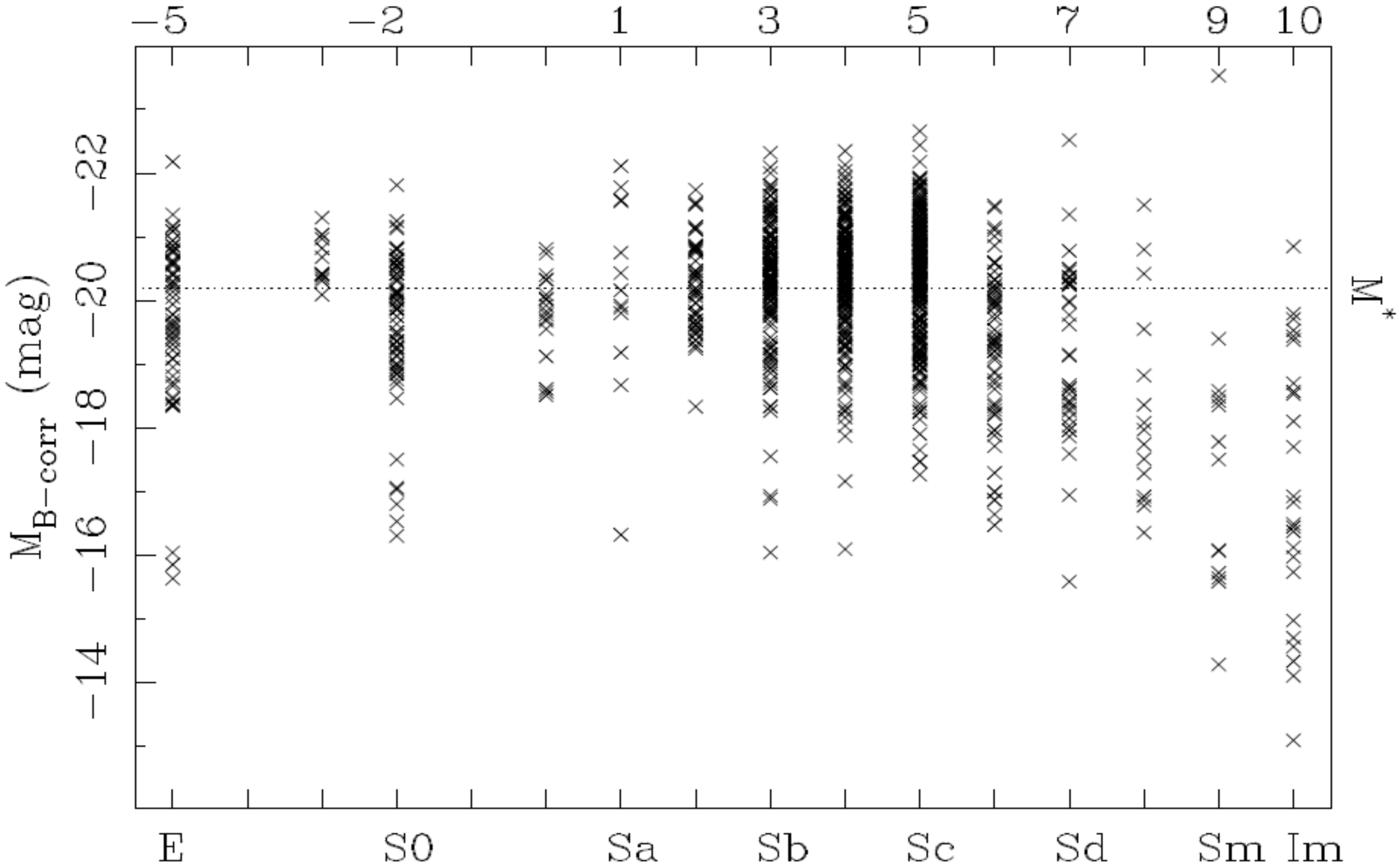
(Sulentic et al. A&A 2006)

5.3 AMIGA project: Morphological type



(Sulentic et al. A&A 2006)

5.3 **AMIGA** project: Morphological type



(Sulentic et al. A&A 2006)

5.4 AMIGA project: Morphological type - OLF

MORFO Results – luminosity

- **majority of sample lies in range -18 to -21**
- **few super L* early types – no merger postcursors**
- **isolated S0/a and Sa are relatively rare**
- **bulk of super L* are Sab-Scd with 63% Sb-Sc**
- **local pop. dominated by very late-type dwarfs**
- **few early type dwarfs in local pop– less isolated?**

bullet **is restricted L range of isolated early types real?**

- **correlation between type and lowest galaxy L from Sa to Im?**

5.5 AMIGA project: Understanding OLFs and M*

- Early-types --- M* depends strongly on environment

  2DFGRS (Croton et al. 2005) --- 1.6 magnitude dimming

  from clusters to voids

- Late-types --- M* insensitive to environment fewer bright S

  in clusters but just as bright as in voids

- M* --- if **S=E or S>E** there can be no "fossil" merger population

- AMIGA has found a modest population of primordial E/S0s?

Isolated early-type ellipticals?

→ Sulentic & Rabaca 1994 – OLF of isolated CIG ellipticals not consistent with a merger population
→ Aars et al. 2001 – Nine CIGs → the really are isolated
→ Marcum et al. 2004 – Nine CIGs → BVR imaging

- n=2 blue, disturbed, tidal features – merger remnants
- n=2 blue but no morphological peculiarities, isolated lenticulars??
- n=2 red, appear to be normal ellipticals

→ Colbert et al. 2001 – Not isolated by CIG definition
→ Hau & Forbes 2004 – Radial kinematics

- a dichotomy in kinematic properties (as generally found)
- low L rotationally supported
- not isolated by CIG definition – a CIG threshold???

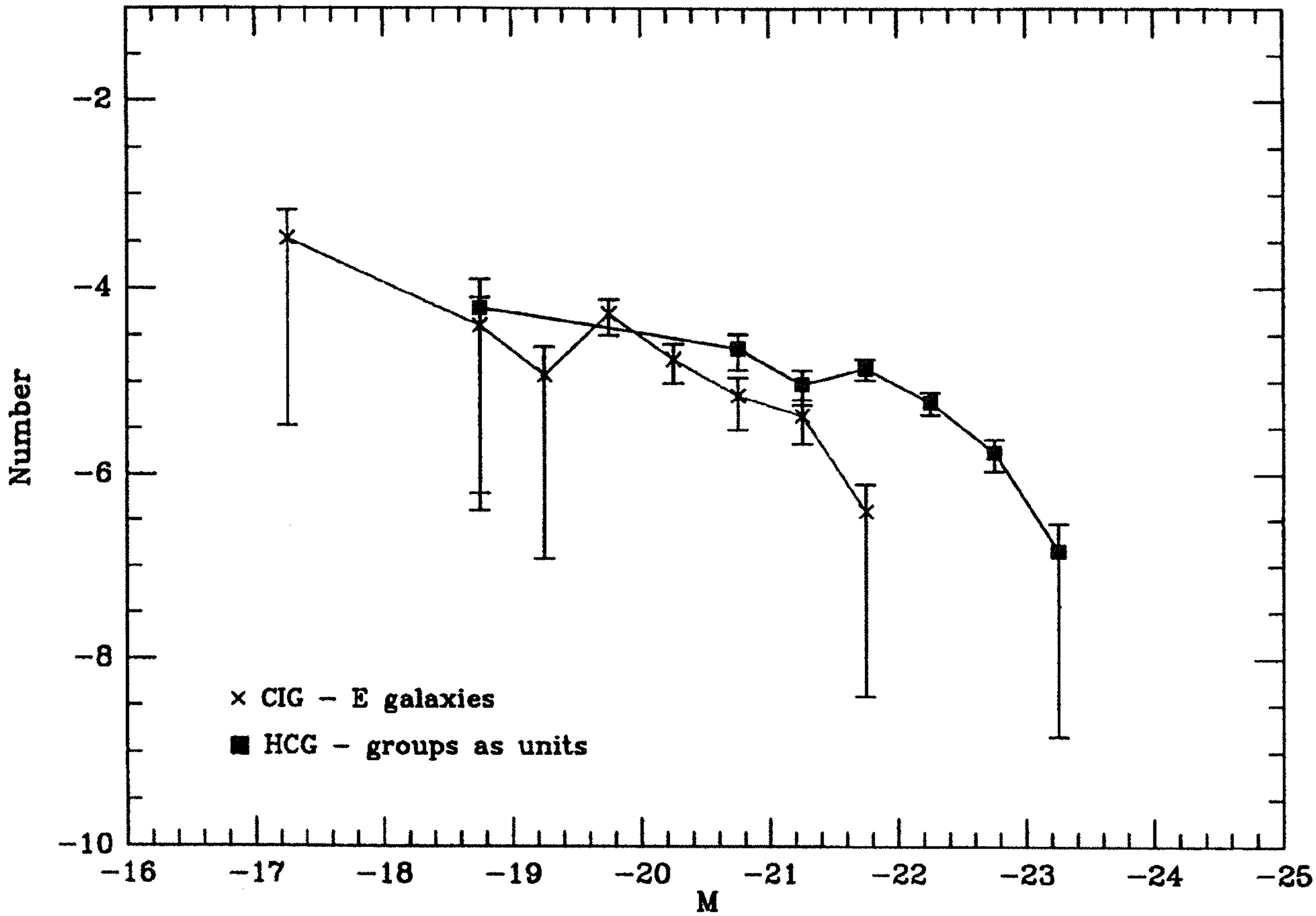
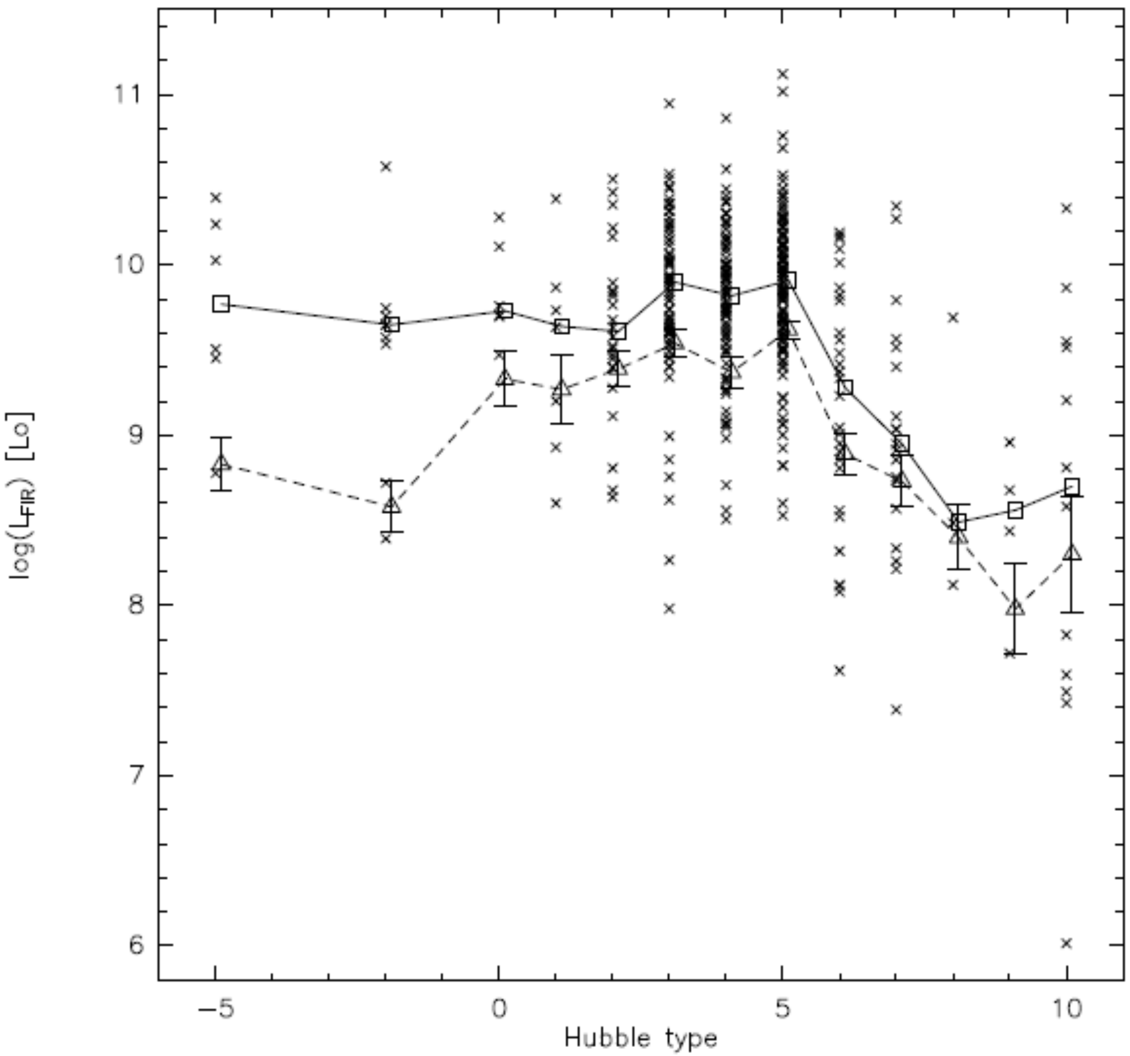


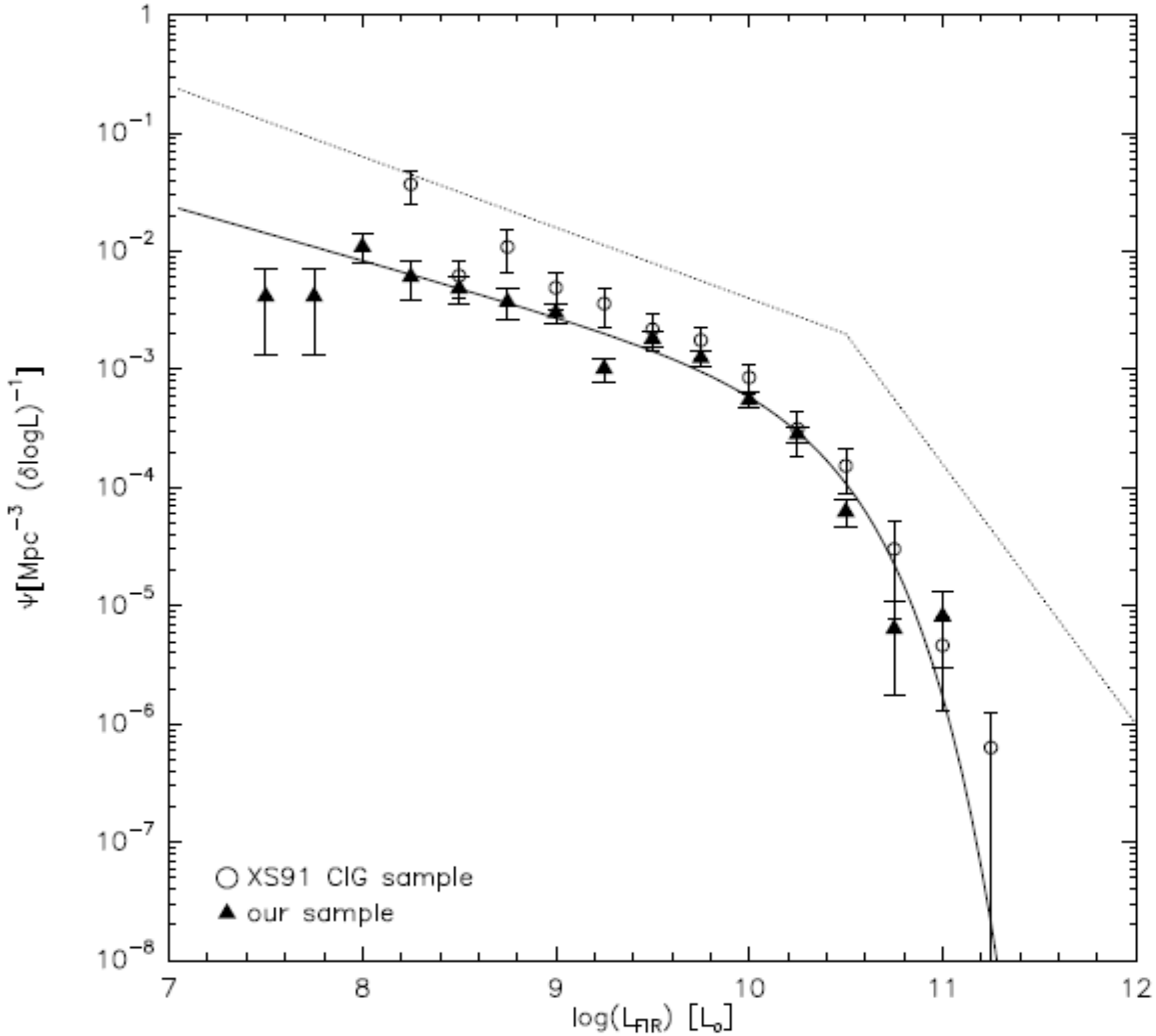
FIG. 8.—Comparison of the type-specific CIG OLF for elliptical galaxies and the OLF for CGs as units (with $\bar{v}_r \leq 12{,}000$ km s^{-1}). Magnitudes for the groups are a straight sum of all components.

5.6 AMIGA project: L_{FIR} vs. Type



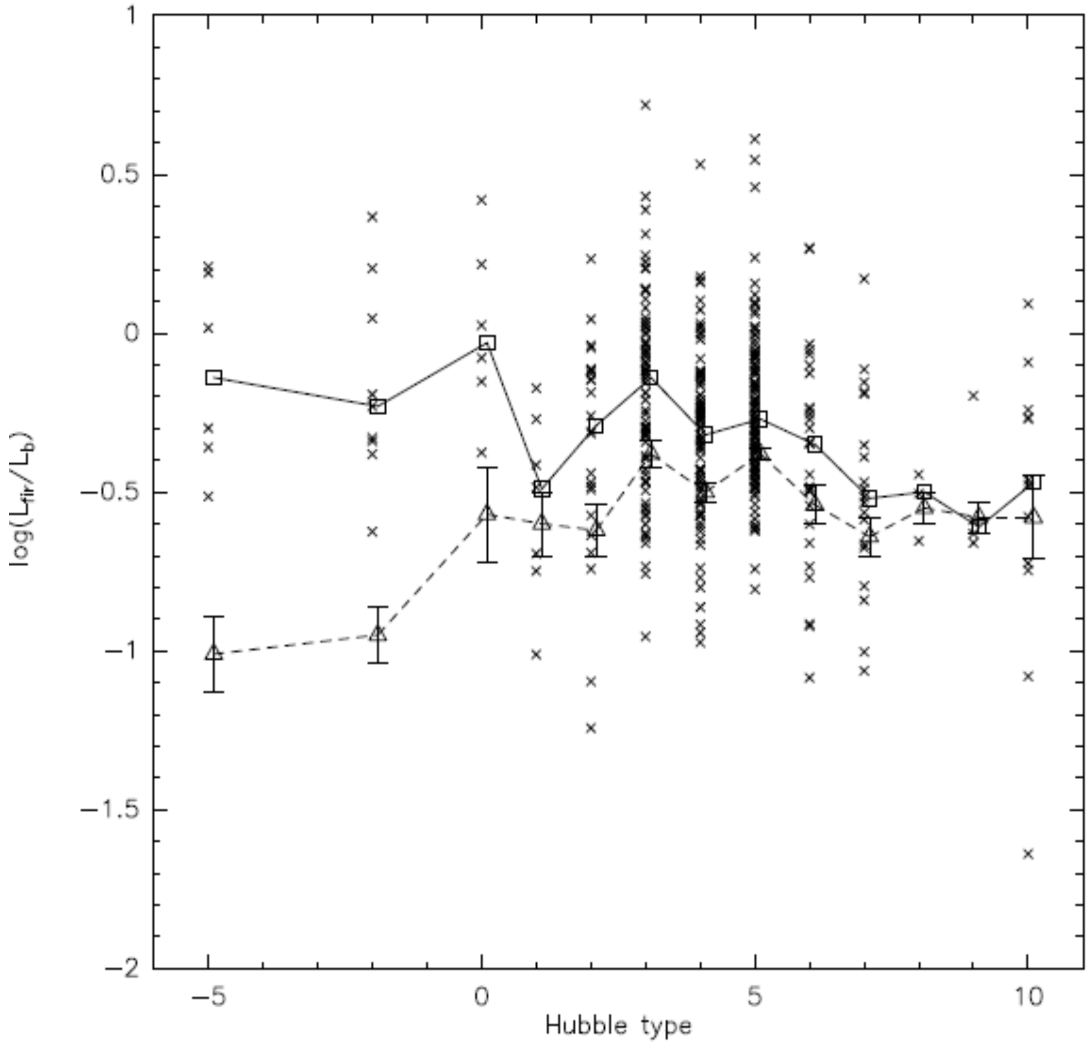
(Lisenfeld et al. 2007, A&A 462 507)

5.6 AMIGA project: FIRLF



(Lisenfeld et al. 2007, A&A 462 507)

5.6 AMIGA project: LFIR/LB vs Type



(Lisenfeld et al. 2007, A&A 462 507)

5.6 AMIGA project: IRAS vs Type

Table 7. Mean and median values of IRAS colours.

(1) Sample	(2) n_{tot}	(3) n_{up}	(4) $< \log(F_{60}/F_{100}) >$ med($\log(F_{60}/F_{100})$)	(5) n_{up}	(6) $< \log(F_{25}/F_{60}) >$ med($\log(F_{25}/F_{60})$)	(7) n_{tot}	(8) n_{up}	(9) $< \log(F_{12}/F_{25}) >$ med($\log(F_{12}/F_{25})$)
Total	468	76	−0.42±0.01 −0.45	343	−0.87± 0.02 −0.83	126	67	−0.33±0.03 −0.18
S/Im (T = 1–10)	443	72	−0.43±0.01 −0.45	326	−0.87±0.02 −0.83	118	65	−0.33±0.03 −0.16
E (−5)	9	3	−0.23±0.06 −0.23	4	−0.73±0.09 −0.74	5	2	−0.47±0.07 −0.48
S0 (−2)	10	1	−0.39±0.06 −0.35	8	−1.02±0.004 −1.02	2	0	−0.16±0.01 −0.16
S0a (0)	6	0	−0.36±0.07 −0.27	5	−0.98• −0.98	1	0	−0.27• −0.27
Sa (1)	9	2	−0.43±0.04 −0.42	7	−0.79±0.05 0.71	2	1	−0.32• −0.32
Sab (2)	27	3	−0.42±0.03 −0.45	18	−0.81±0.04 −0.72	9	4	−0.39±0.09 −0.22
Sb (3)	88	15	−0.41±0.02 −0.44	63	−0.87±0.03 −0.89	25	17	−0.50±0.10 −0.18
Sbc (4)	104	17	−0.45±0.01 −0.46	77	−0.83±0.03 −0.78	27	15	−0.27±0.04 −0.15
Sc (5)	138	24	−0.46±0.01 −0.48	107	−0.87±0.03 −0.88	32	14	−0.24±0.05 −0.10
Scd (6)	34	6	−0.45±0.02 −0.44	24	−0.87±0.06 −0.82	10	6	−0.36±0.08 −0.17
Sd (7)	21	2	−0.39±0.03 −0.40	13	−0.85±0.07 −0.79	8	5	−0.23±0.003 −0.23
Sdm (8)	4	1	−0.40±0.02 −0.40	3	−0.70±0.15 −0.34	1	1	– –
Sm (9)	5	1	−0.27±0.02 −0.28	3	−1.19±0.08 −1.24	2	1	−0.28±0.04 −0.22
Im (10)	13	1	−0.31±0.03 −0.35	11	−0.95±0.08 −0.80	2	1	−0.09±0.10 0.06
Interacting	14	2	−0.36±0.03 −0.39	10	−0.87± 0.03 −0.89	4	0	−0.32±0.08 −0.34

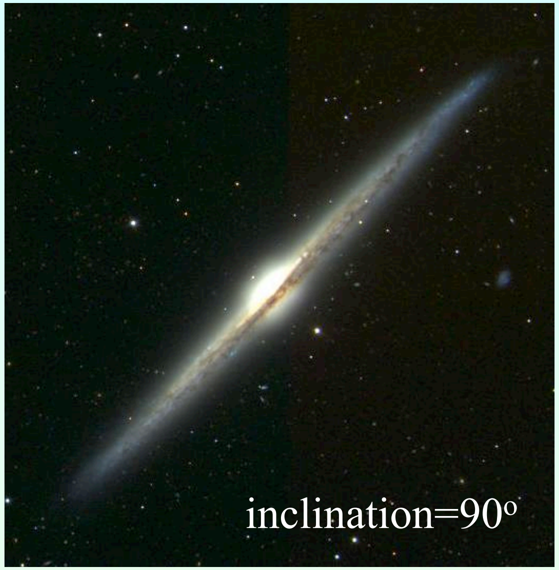
FOCUSSING ON TYPICAL ISOLATED GALAXIES

- Durbala et al. 2008 – surface photometry
- Durbala et al. 2009? – Fourier analysis

Sample selection

- Sb-Sc CIG galaxies
- $1500 < v_R < 10\ 000$ km/s
- $m_{B\ corr} < 15$
- inclination < 70^o
- available i-band images in SDSS DR6

100 Sb-Sc galaxies.



inclination=90^o

inclination=0^o

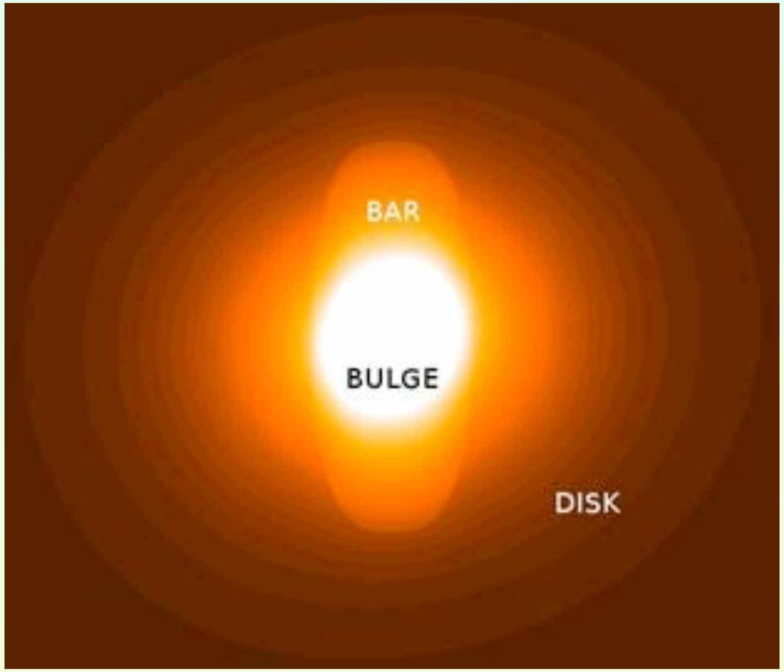
Photometric Characterization

- bulge/disk/bar decomposition
- CAS (Concentration/Asymmetry /Clumpiness) parametrization
- Fourier decomposition/analysis

Bulge/Disk /Bar Image Decomposition

- performed using the new version of **BUDDA**

(**BU**lge/**D**isk **D**ecomposition **A**nalysis)- de Souza et al. 2004 using SDSS i-filter images



• **Disk**:

$$I(r) = I_o e^{-r/h_R}$$

(Exponential profile)

• **Bulge** & **Bar**:

(Sérsic profile)

$$I(r) = I_e 10^{-b_n[(r/r_e)^{1/n} - 1]}$$

Bulge/Disk /Bar Image Decomposition

- performed using the new version of **BUDDA**

(**BU**lge/**D**isk **D**ecomposition **A**nalysis)- de Souza et al. 2004 using SDSS i-filter images

• **Disk**:

$$\mu(r) = \mu_o + 1.086 r / h_R \longrightarrow$$

(Exponential profile)

μ_o – central surface brightness

h_R – radial scalelength

• **Bulge** & **Bar**:

$$\mu(r) = \mu_e + c_n \left[(r/r_e)^{1/n} - 1 \right] \longrightarrow$$

(Sérsic profile)

For **n= 1** Sérsic profile becomes *exponential profile*

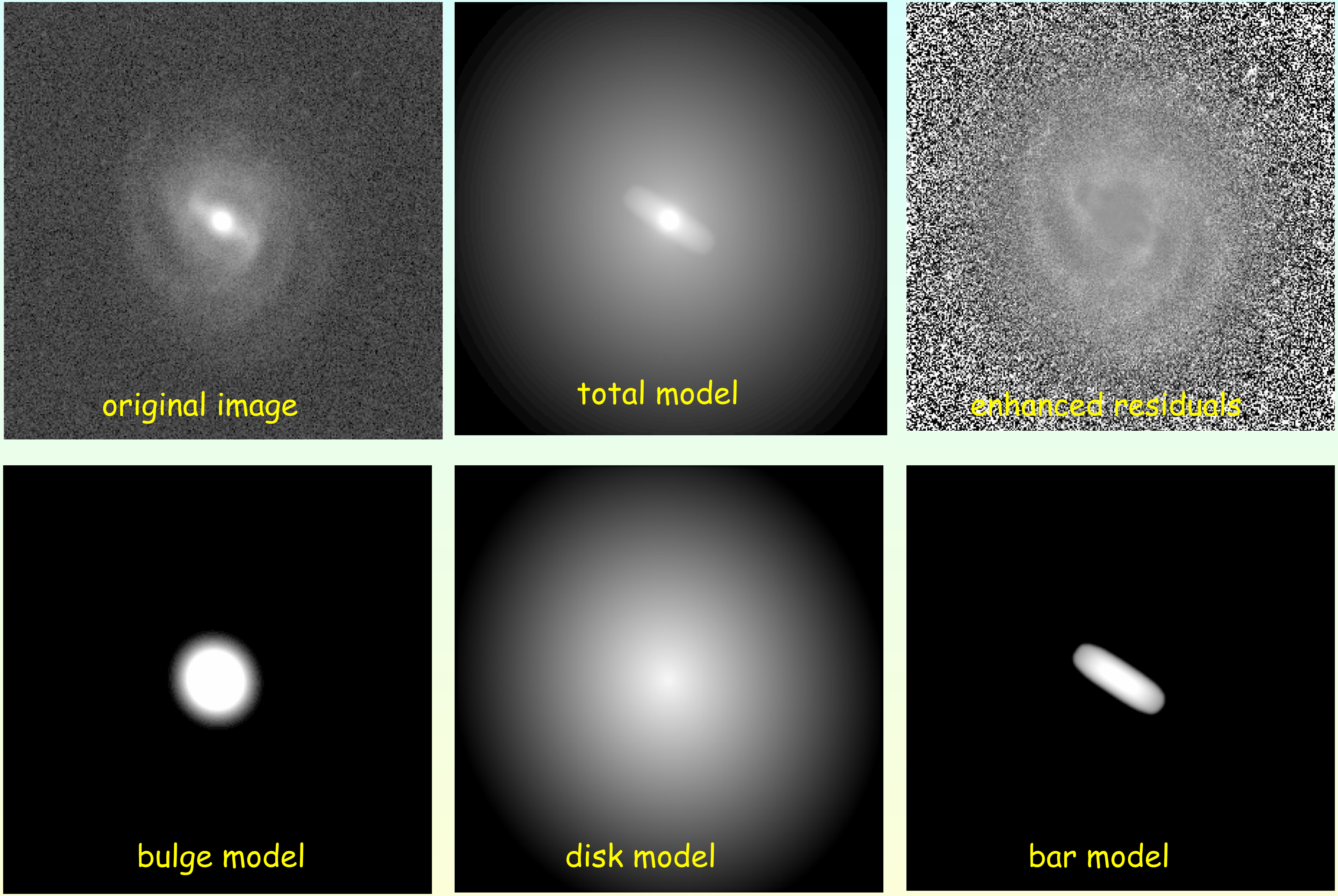
For **n= 4** Sérsic profile becomes *de Vaucouleurs profile*

μ_e - effective surface brightness

r_e – effective radius

n – Sérsic index

KIG 612

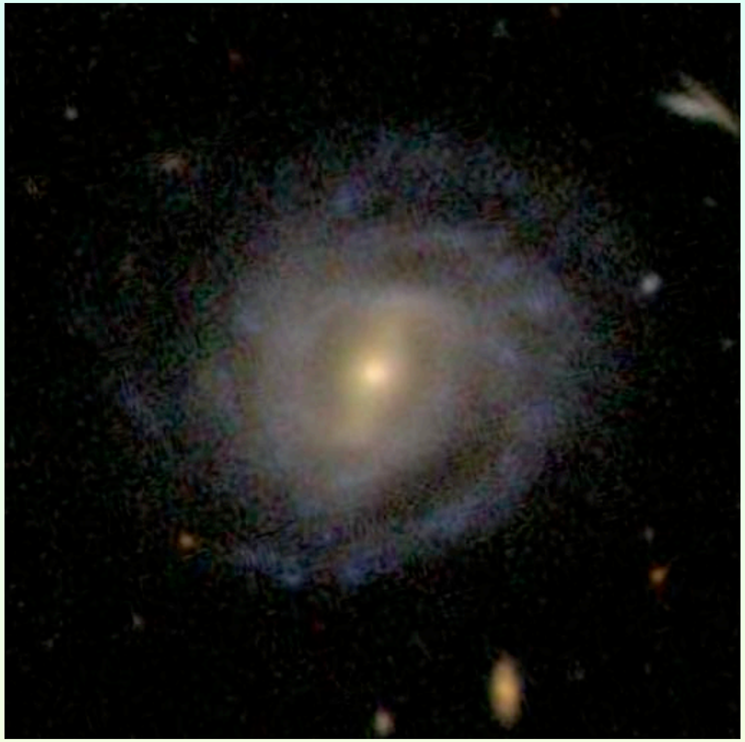

original image
total model
enhanced residuals
bulge model
disk model
bar model

KIG 612

Bulge/Total Lum.=15%

Disk/Total Lum.=77%

Bar/Total Lum.=8%



Bulge: r_e=2.56”

μ_e=20.24 mag arcsec^{-2}

n_{bulge}=0.86

Disk: h_R=12.71”

μ_o=19.69 mag arcsec^{-2}

Bar: l_{bar}=13.88”

n_{bar}=0.44

Bulges of spiral galaxies: classical and pseudobulges

Classical bulges – resemble (in terms of light profiles) giant elliptical galaxies (Typically have large **n** values for Sérsic profiles; ex. de Vaucouleurs, n=4)

Pseudobulges – low **n** (n< 2.5) values for the Sérsic profiles

(recall for n=1, Sérsic becomes exponential)

OUR SAMPLE ⇒ 94% pseudobulges

(Durbala et al. 2008 MNRAS, 390, 881)

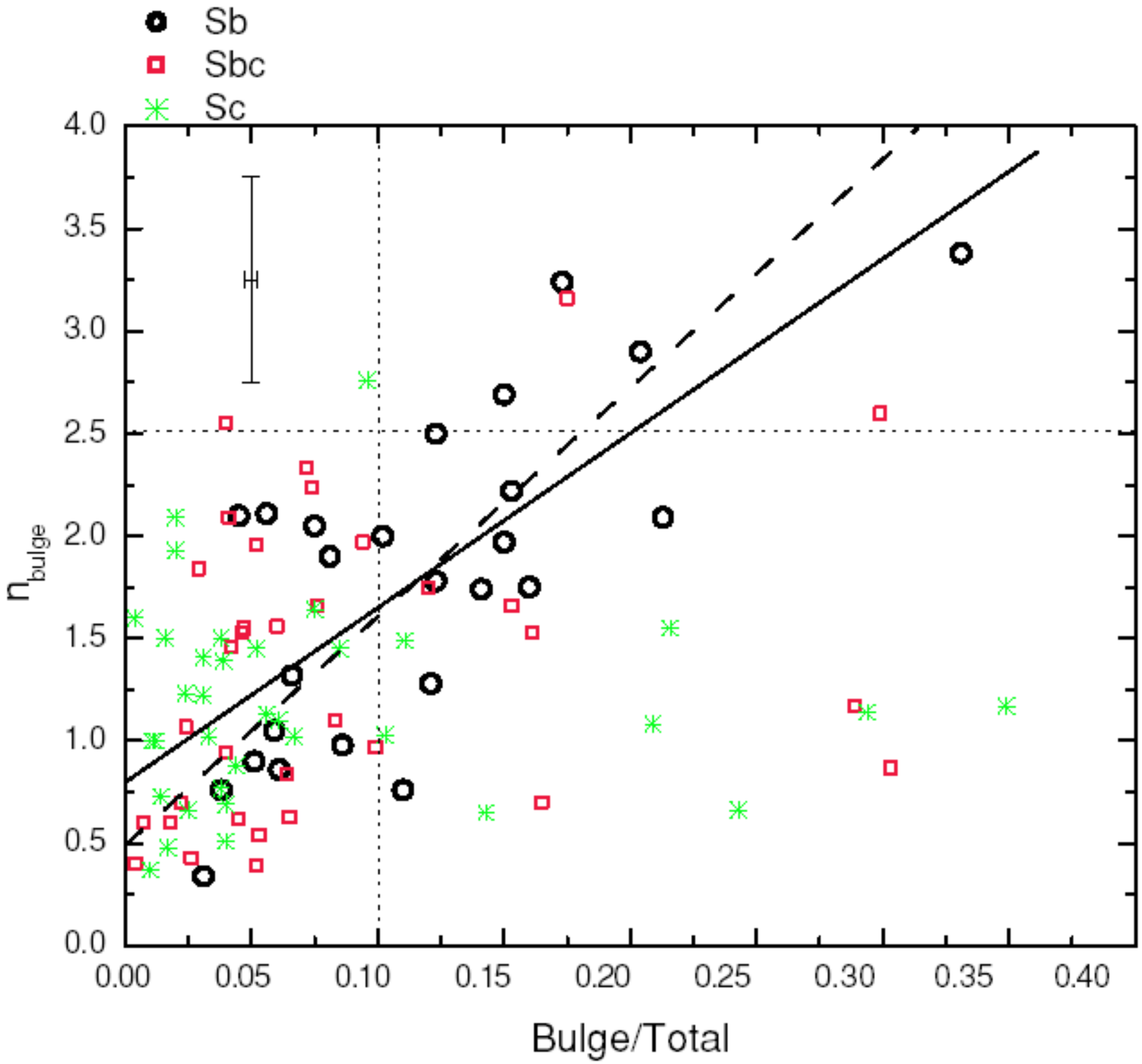
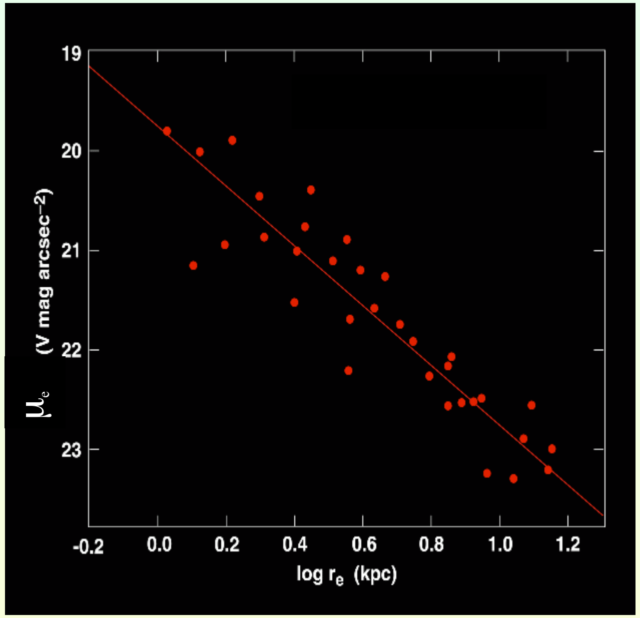


Figure 4. Bulge Sérsic index versus bulge/total luminosity ratio. A linear regression fit (solid line) and a bisector fit (dashed line) are shown for Sb-type only. The typical 2σ errorbars are shown.

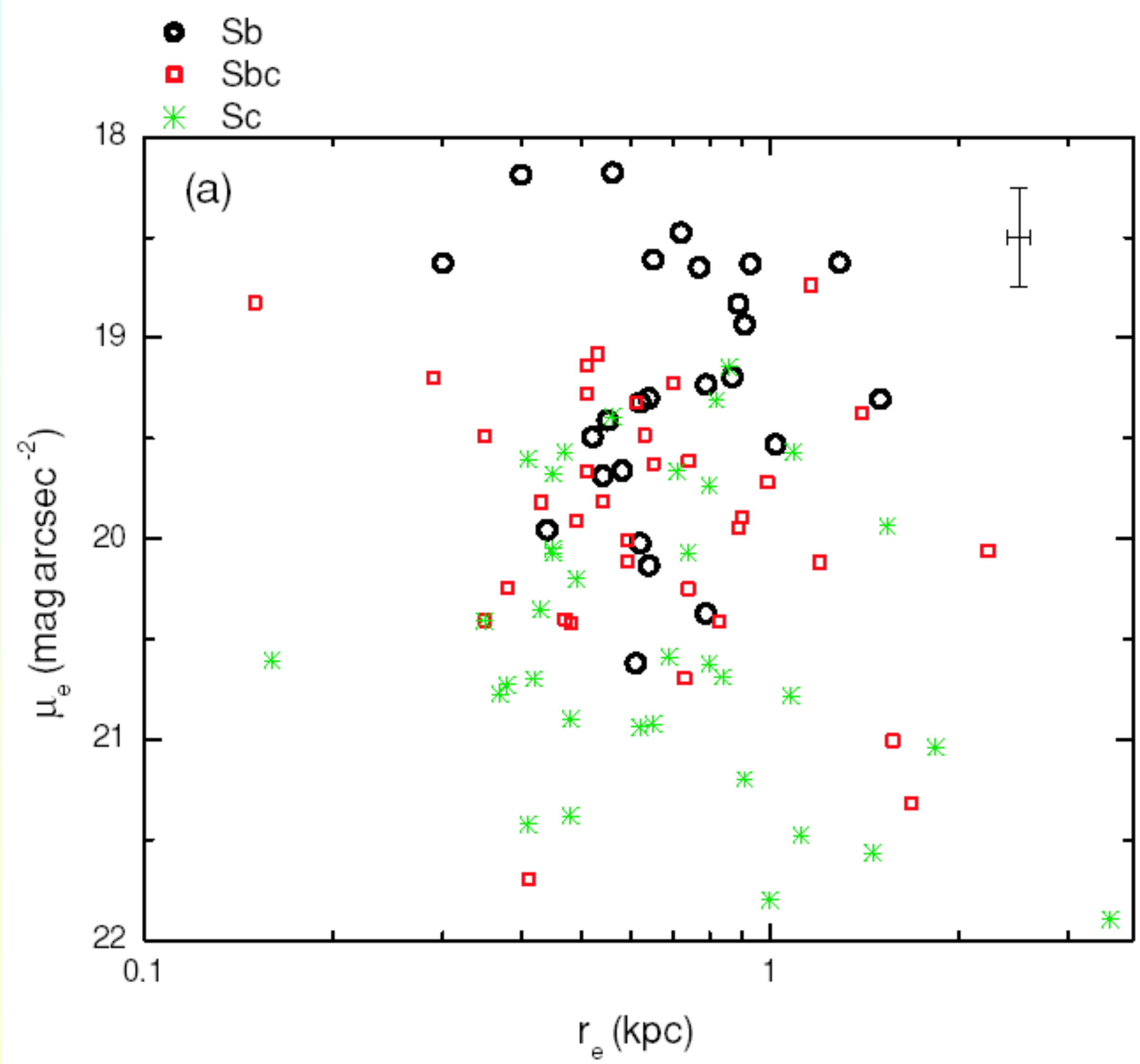
Durbala et al. 2008 MNRAS, 390, 881

-most isolated galaxies in our sample host **pseudobulges**:

- lack of correlations between μ_e and r_e (part of the fundamental plane)



Kormendy (1977)



Durbala et al. 2008 MNRAS, 390, 881

Pseudobulges – suggested to have formed by secular evolution (internal, intrinsic processes)

↓

Expect correlations between the main structural components of the galaxy: bulge, disk, bar

Classical bulges – product of mergers

FAVORS BOTTOM-UP GALAXY

FORMATION?

Photometric Characterization

- bulge/disk/bar decomposition
- CAS (Concentration/Asymmetry /Clumpiness) parametrization
- Fourier decomposition/analysis

CAS parameters

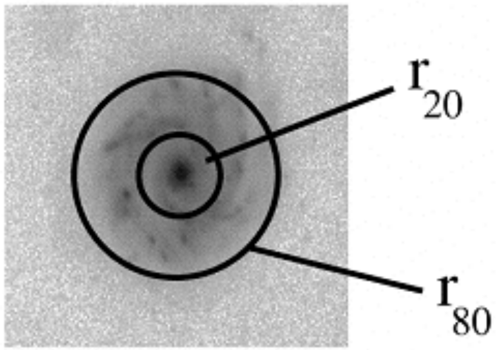
C – concentration

A – asymmetry

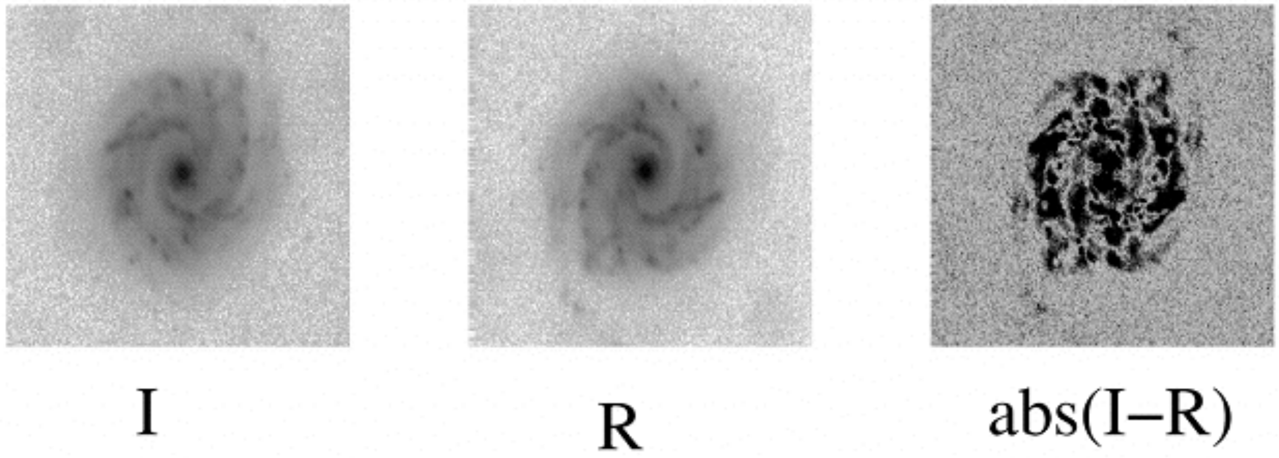
S – clumpiness

Exploited as part of an alternative classification of galaxies (e.g. Bershady, Jangren & Conselice 2000)

Concentration Index



$$C = 5\log\left(\frac{r_{80}}{r_{20}}\right)$$



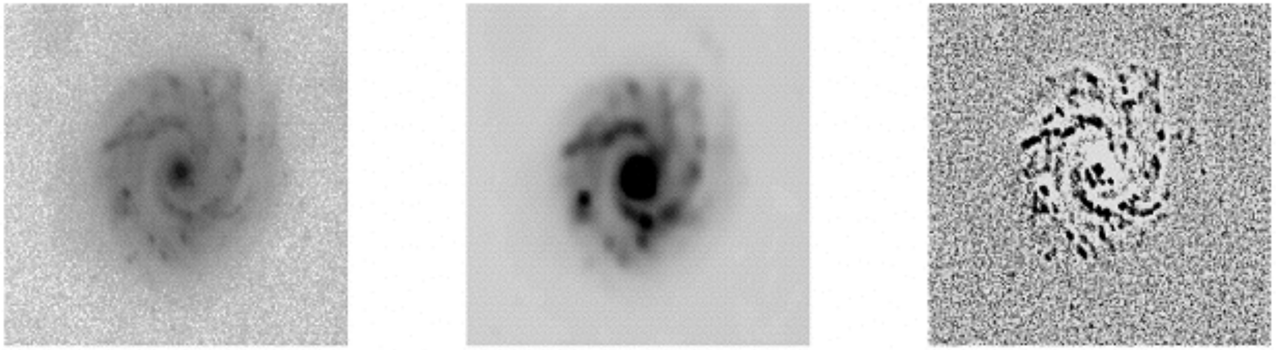
Asymmetry Index

$$A = \frac{\mathrm{abs}(I-R)}{I}$$

R = rotated image with 180°

The High-Spatial Frequency Clumpiness Parameter

Clumpiness Index



I B I–B

$$S = \frac{I-B}{I}$$

B = image "blurred/ smoothed" by a filter

CAS parameters – sensitive to the environment

	C		A		S	
	Mean ± SE	median	Mean ± SE	median	Mean ± SE	median
This study	3.06 ± 0.06	2.89	0.09 ± 0.01	0.08	0.20 ± 0.01	0.20
Conselice (2003)	3.47 ± 0.08	3.44	0.14 ± 0.01	0.13	0.28 ± 0.02	0.25

Durbala et al. 2008 MNRAS, 390, 881

Photometric Characterization

- bulge/disk/bar decomposition
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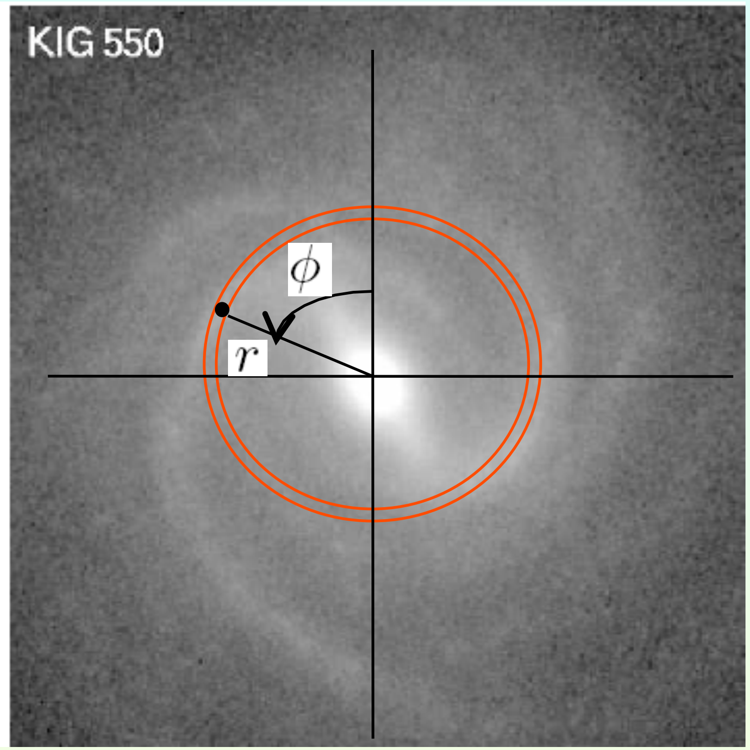
Bar-Spiral separation



$$I(r,\phi) = I_0(r) + \sum_{m=1}^{\infty} I_m(r)\cos[m(\phi - \phi_m)]$$

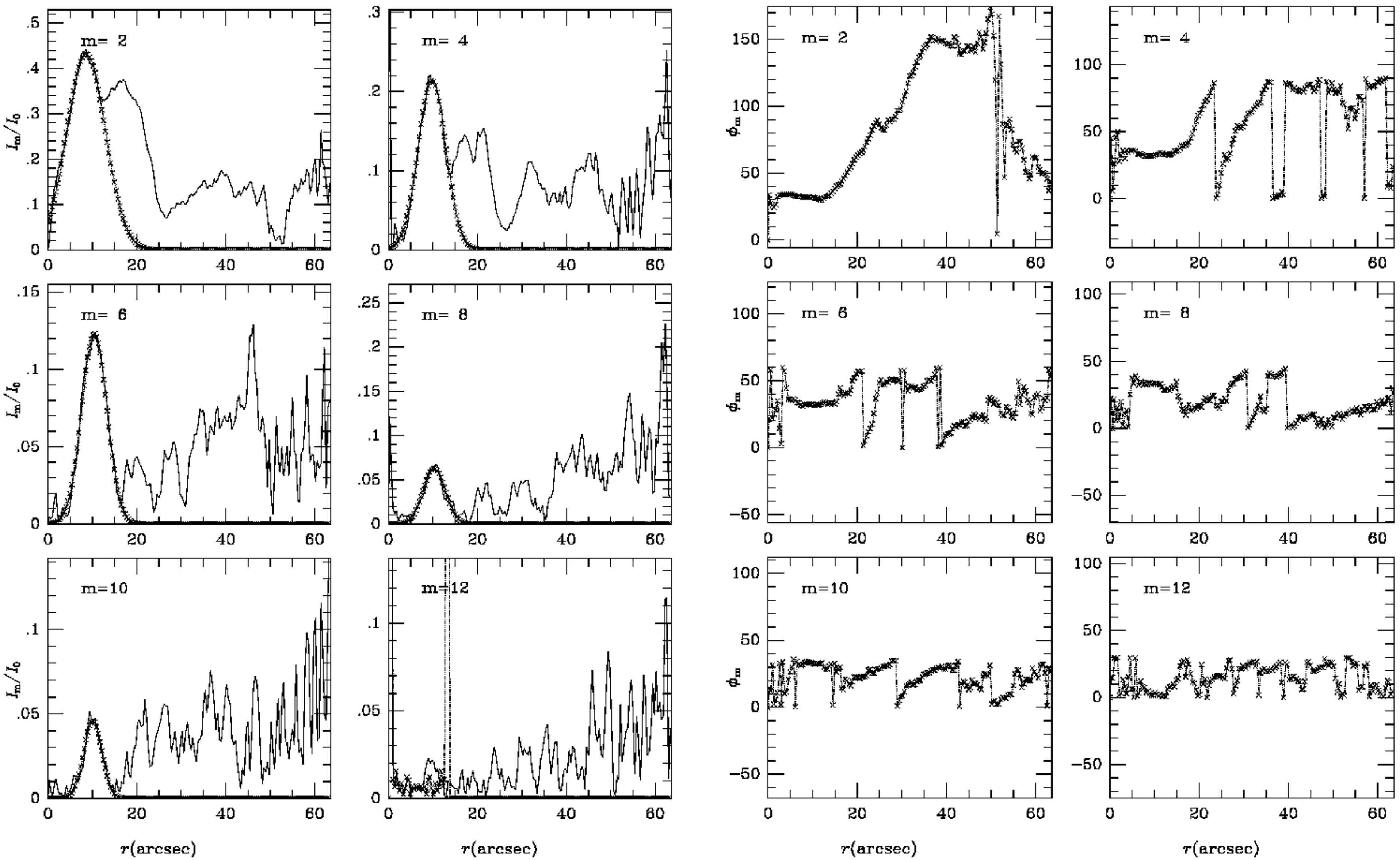


Figure 1. KIG 550: (*left*): Relative Fourier intensity amplitudes I_m/I_0 for the first six even Fourier terms (m=2 to m=12); (*right*): Phase profiles ϕ_m for the first six even Fourier terms (m=2 to m=12).

Bar contrast

$$A_{mb} = \left(\frac{I_m}{I_0}\right)_{max}$$

Ex: $A_{2b} = \left(\frac{I_2}{I_0}\right)_{max}$; $A_{4b} = \left(\frac{I_4}{I_0}\right)_{max}$

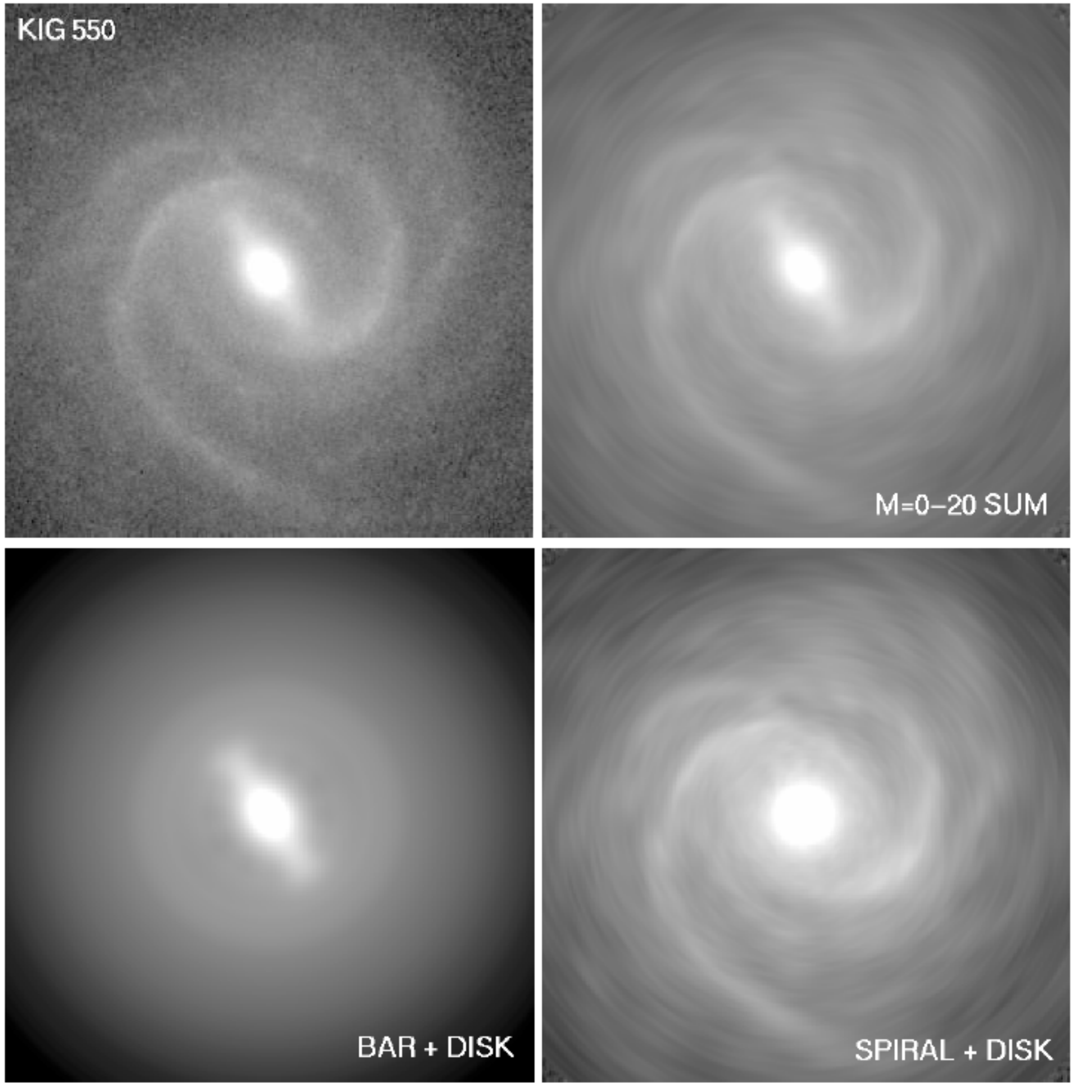


Figure 2. KIG 550: ($upper-left$) original reduced/deprojected i-band image; ($upper-right$) "M=0-20 SUM" image ("Fourier-smoothed" version of the original image) = the sum of the 21 Fourier terms; ($lower-left$) "BAR + DISK" image = the sum of the bar image and m=0 image; ($lower-right$) "SPIRAL + DISK" image = "M=0-20 SUM" image minus the bar image.

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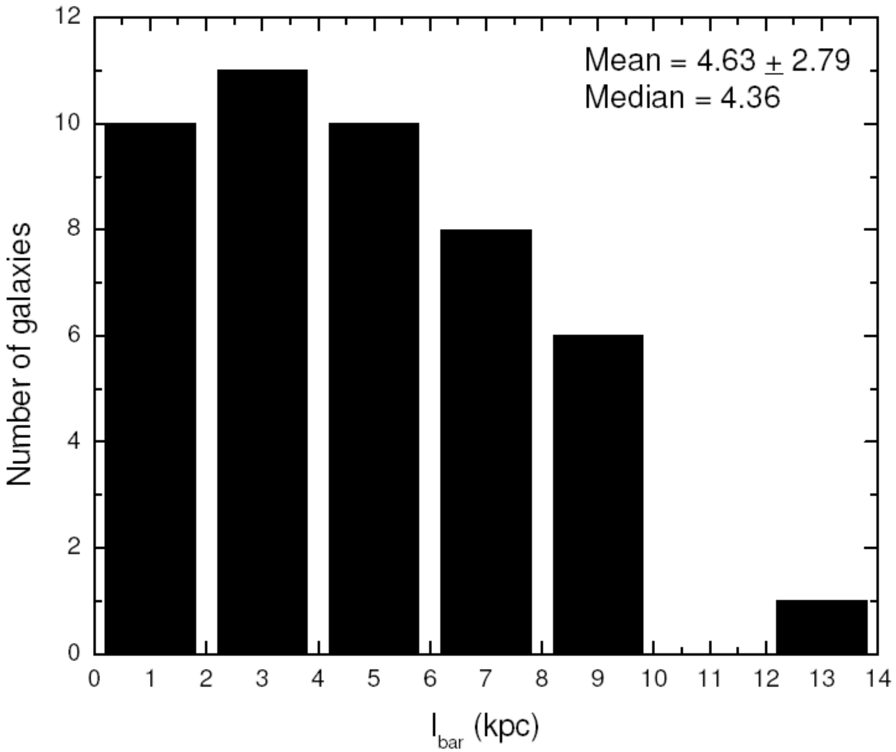
Table 3. Mean/Median for Strength Parameters of **Barred** Galaxies in our sample

Type (N)	Q_b mean±SE median		Q_s mean±SE median		Q_g mean±SE median		A_{2b} mean±SE median		l_{bar} (kpc) mean±SE median	
Sb (22)	0.261±0.022	0.225	0.146±0.011	0.152	0.298±0.019	0.286	0.51±0.03	0.51	6.19±0.51	5.94
Sbc (10)	0.206±0.031	0.205	0.164±0.026	0.124	0.232±0.030	0.232	0.32±0.07	0.29	4.44±0.86	4.36
Sc (14)	0.242±0.033	0.235	0.199±0.013	0.186	0.282±0.027	0.273	0.25±0.04	0.22	2.32±0.43	2.01
Sb-Sc (46)	0.243±0.015	0.222	0.166±0.009	0.165	0.279±0.014	0.273	0.39±0.03	0.38	4.63±0.41	4.36

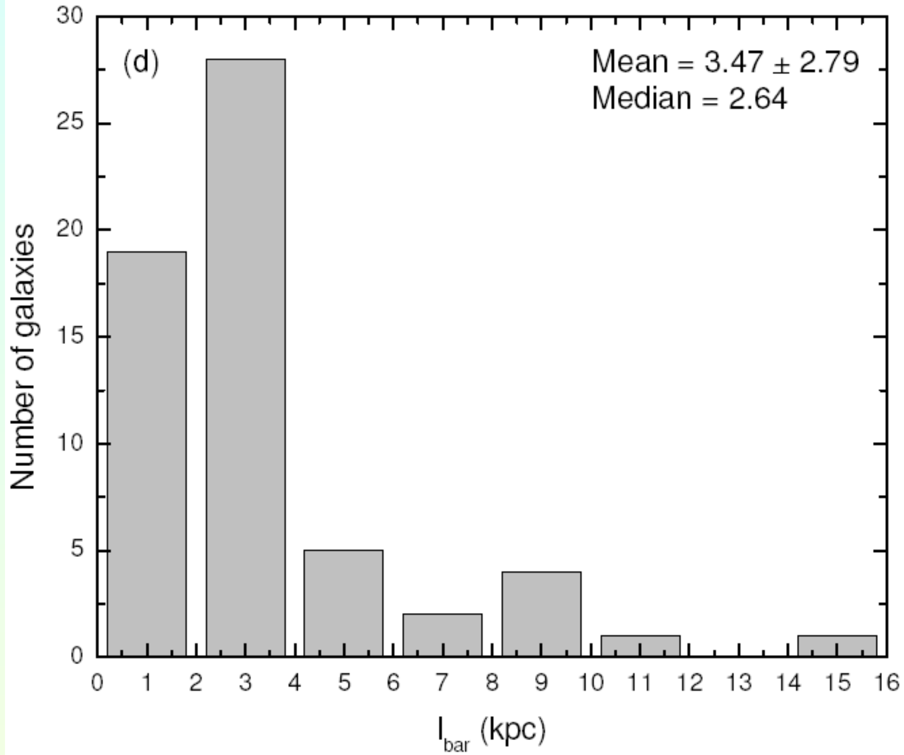
Column (1): galaxy name. Column (2): bar strength. Column (3): spiral arm strength. Column (4): total strength. Column (5): $A_{2b} = (I_2/I_0)_{max}$. Column (6) length of the bar in kpc.

Note: N=number of galaxies; *SE* is standard deviation of the mean.

<u>CIG</u>



<u>OSUBGS</u>



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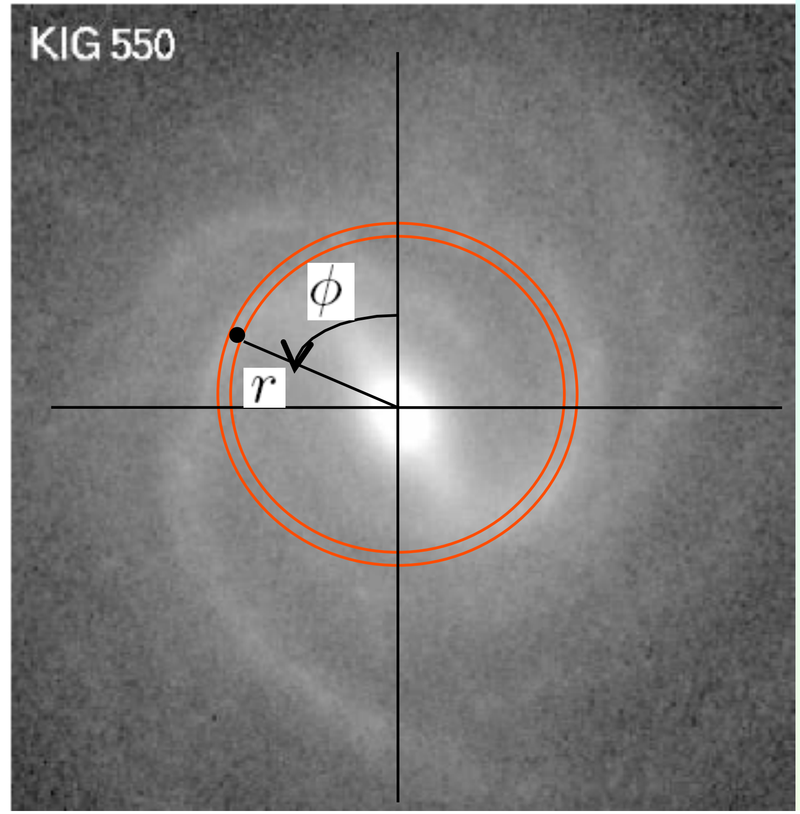
Images for the individual m Fourier terms:



$$I(r,\phi) = I_0(r) + \sum_{m=1}^{\infty} I_{mc}(r)\cos m\phi + \sum_{m=1}^{\infty} I_{ms}(r)\sin m\phi$$

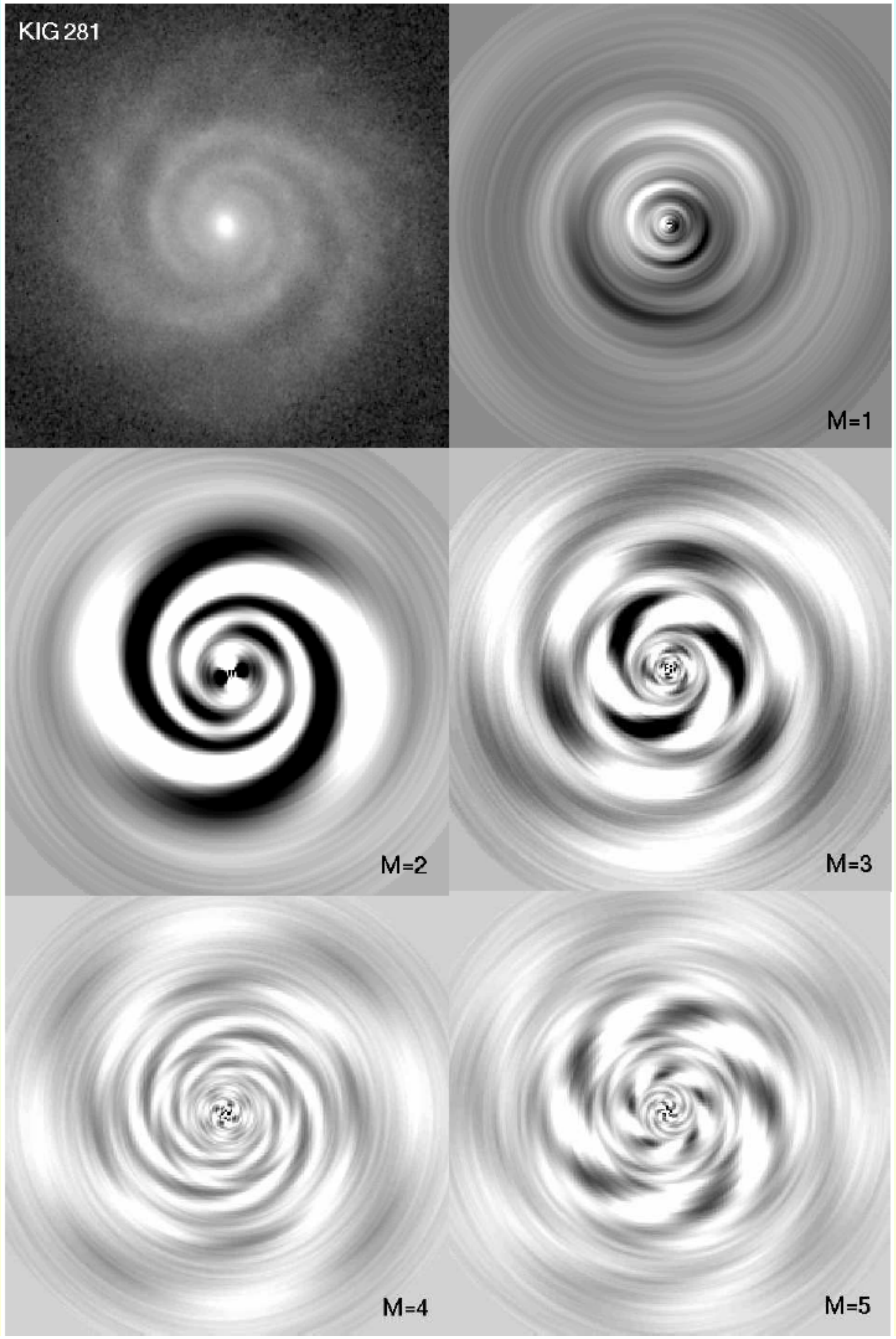
Ex:

m=1 image is given by : $I_{1c}(r)\cos\phi + I_{1s}(r)\sin\phi$

m=2 image is given by : $I_{2c}(r)\cos 2\phi + I_{2s}(r)\sin 2\phi$

m=2

spiral arm multiplicity



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Spiral Arm multiplicity

CIG

28 % galaxies → only m= 2 & 3

CSRG (Catalog of Southern Ringed Galaxies; Buta 1995)

6-8 % galaxies → only m= 2 & 3

"Perhaps three-arm structures will provide a good measure of the time that has elapsed since a tidal interaction" – Elmegreen, Elmegreen & Montenegro 1992

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Conclusions

- CIG/AMIGA sample is dominated by spiral galaxies (82%)
- The bulk is Sb-Sc (63%)
- most Sb-Sc galaxies (up to 94%) host pseudobulges (i.e. “disky”) rather than classical bulges
- the properties of pseudobulges/bars and disks are correlated (secular evolution)
- bars may help the formation of pseudobulges
- Sb are redder, brighter, have larger disks and longer bars, more luminous bulges, more concentrated, more symmetric than Sbc-Sc
- isolated galaxies Sb-Sc host longer bars, are more symmetric, less concentrated and less clumpy than Sb-Sc from less isolated samples.

- longer bars show higher contrast, but are not necessarily stronger than shorter ones
- bar and spiral components are dynamically independent
- Fourier decomposition can reveal surprising cases of counter-winding spiral structure (KIG 652/NGC 5768)