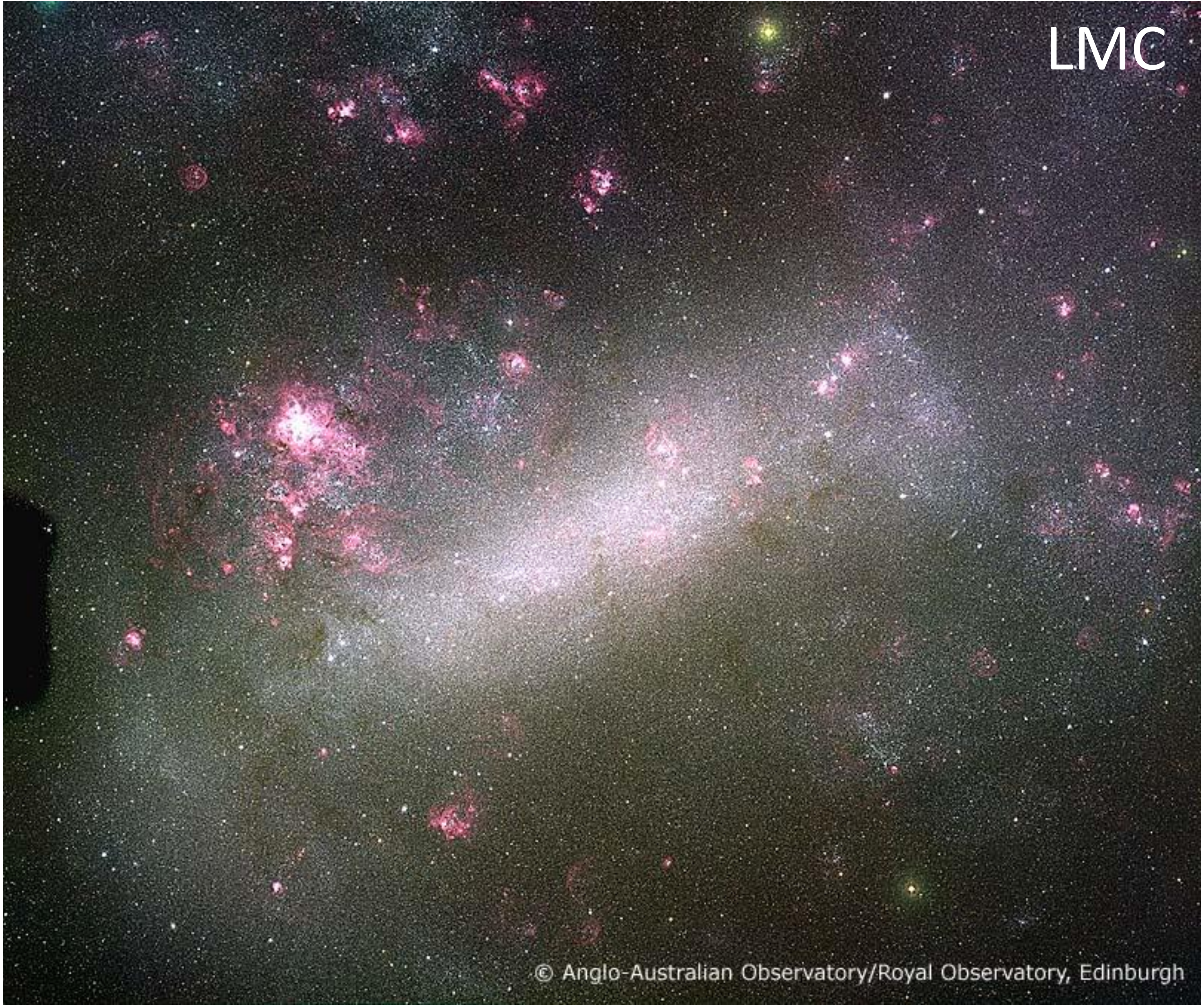
Extragalactic star clusters

- Star clusters are found for almost all galaxy types
- Either “Globulars” (far away from the disk/center) or star forming regions (bright) observed
- Examples:
  1. NGC 5128 (elliptical), about 1600 GCLs; Harris et al., 2006, AJ, 132, 2187
  2. NGC 628 (spiral), complete Young Cluster Population; Adamo et al., 2017, ApJ, 841, 131
  3. M31 (Andromeda Galaxy), 1200 GCLs; Galleti et al., 2004, A&A, 416, 917
- Review: Brodie & Strader, 2006, ARA&A, 44, 193



6 Degrees on the sky

5.4 Degrees on the Sky

4 Arc minutes

30 Dor:

Star cluster in the LMC

4850 listed in Bitsakis et al., 2017, ApJ, 845, 56

NGC 1866

LMC, age about 100 Myr

NGC 2298

Milky Way, age about 15 Gyr

Open clusters in the MCs have the same morphology as GCs in the Milky Way

Distance and Reddening

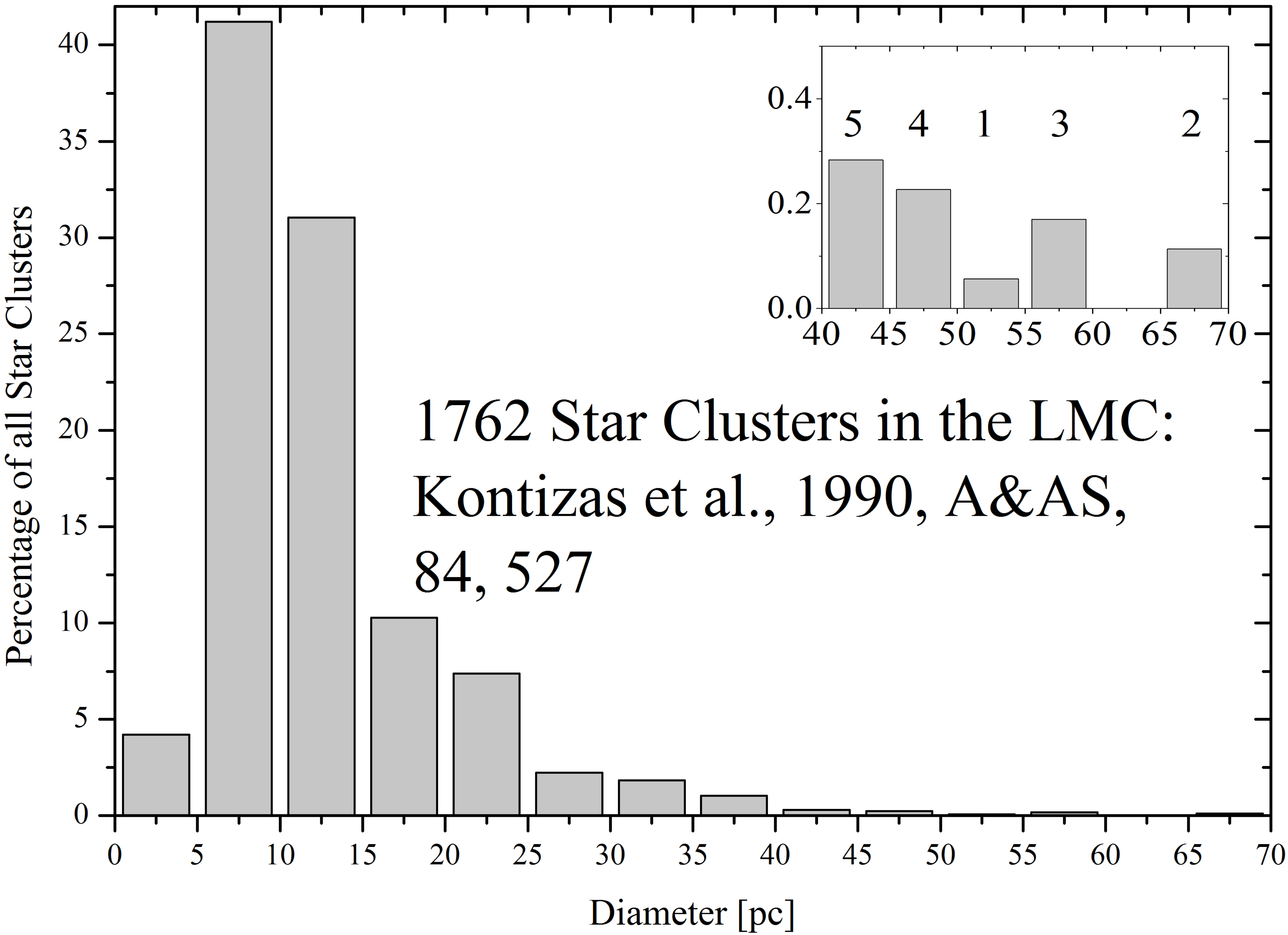
- LMC:
  - $V-M_V = 18.5$ mag
  - $E(B-V) = 0.05$ to 0.1 mag
  - Distance about 50 kpc
- SMC:
  - $V-M_V = 19.0$ mag
  - $E(B-V) = 0.05$ to 0.1 mag
  - Distance about 60 kpc
- Intrinsic reddening up to 0.2 mag for "normal" regions in the bulge

Characteristics

- Irregular Galaxies
- Disintegrate because of gravitational interaction with the MW
- Global elemental abundance is lower than in the MW: $-2 < [Fe/H] < -0.3$ dex
- Total masses about 20 times lower than in the MW
- Global magnetic field lower than in the MW

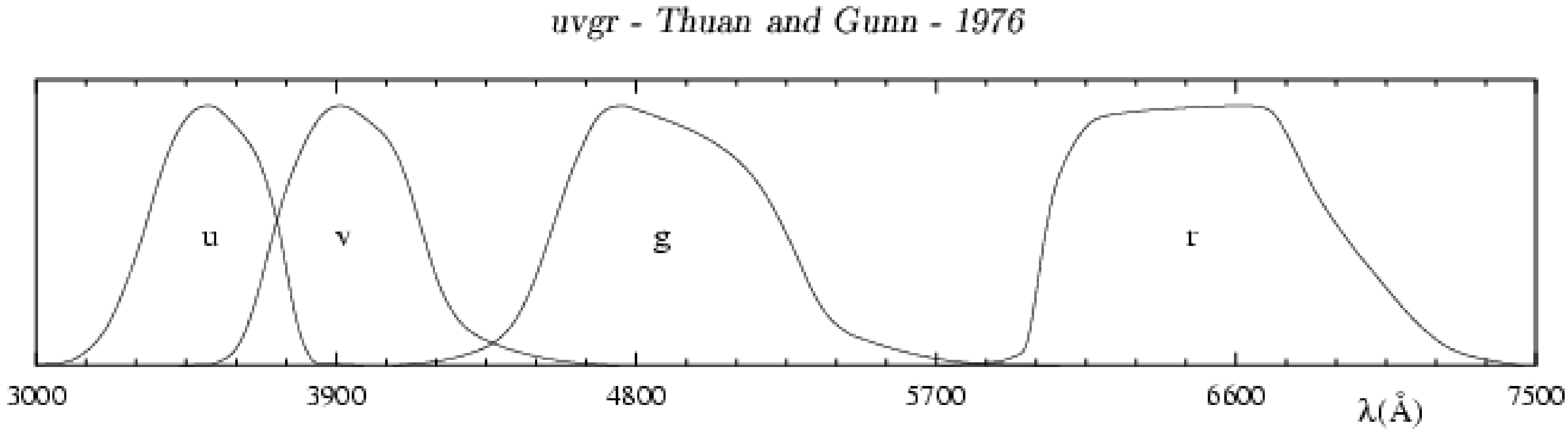
	Cluster	SWB class	R (arcsec)	$N_{\rm star}$	$V_{\rm TO}$ (mag)	age (Myr)
LMC	KMHK265	...	30	303	16.5	$50 \div 100$
	NGC 1902	II	40	440	17	$100 \div 150$
	KMHK264	...	30 7 pc	241	17.5	$150 \div 200$
	NGC 1777	IV B	$25 \div 70$	804	19.5	$700 \div 800$
	IC 2146	V	60	2023	20.25	$1200 \div 1500$
	NGC 2155	VI	$16 \div 50$	1085	20.5	$1500 \div 2000$
SMC	NGC 299	...	25	271	14.5	$15 \div 20$
	NGC 220	III	30	511	16.5	$70 \div 100$
	NGC 222	II-III	25	361	16.5	$70 \div 100$
	NGC 231	...	30	449	16.5	$70 \div 100$
	NGC 458	III	65	1288	17.0	$100 \div 150$
	L45	...	30	334	17.0	$100 \div 150$
	L13	...	35	300	19.25	$450 \div 550$
	NGC 643	...	70 20 pc	1127	19.5	$600 \div 700$
	L9	...	35	374	$20.25 \div 20.5$	$1000 \div 1300$
	NGC 152	IV B	60	1862	$20.25 \div 20.5$	$1000 \div 1300$

Matteucci et al., 2002, A&A, 387, 861


1762 Star Clusters in the LMC:
Kontizas et al., 1990, A&AS, 84, 527
Percentage of all Star Clusters
Diameter [pc]
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
0.0
0.2
0.4
5
4
1
3
2

- Impact for the study of star clusters in the Magellanic Clouds
    1. The diameters of star clusters are normally below 1’
    2. The core regions are difficult to resolve
    3. The distance is no free parameter any more
    4. There are almost no “foreground objects”
    5. The membership determination on a kinematical basis is almost impossible
    6. Star clusters are most suitable to perform “statistical investigations”

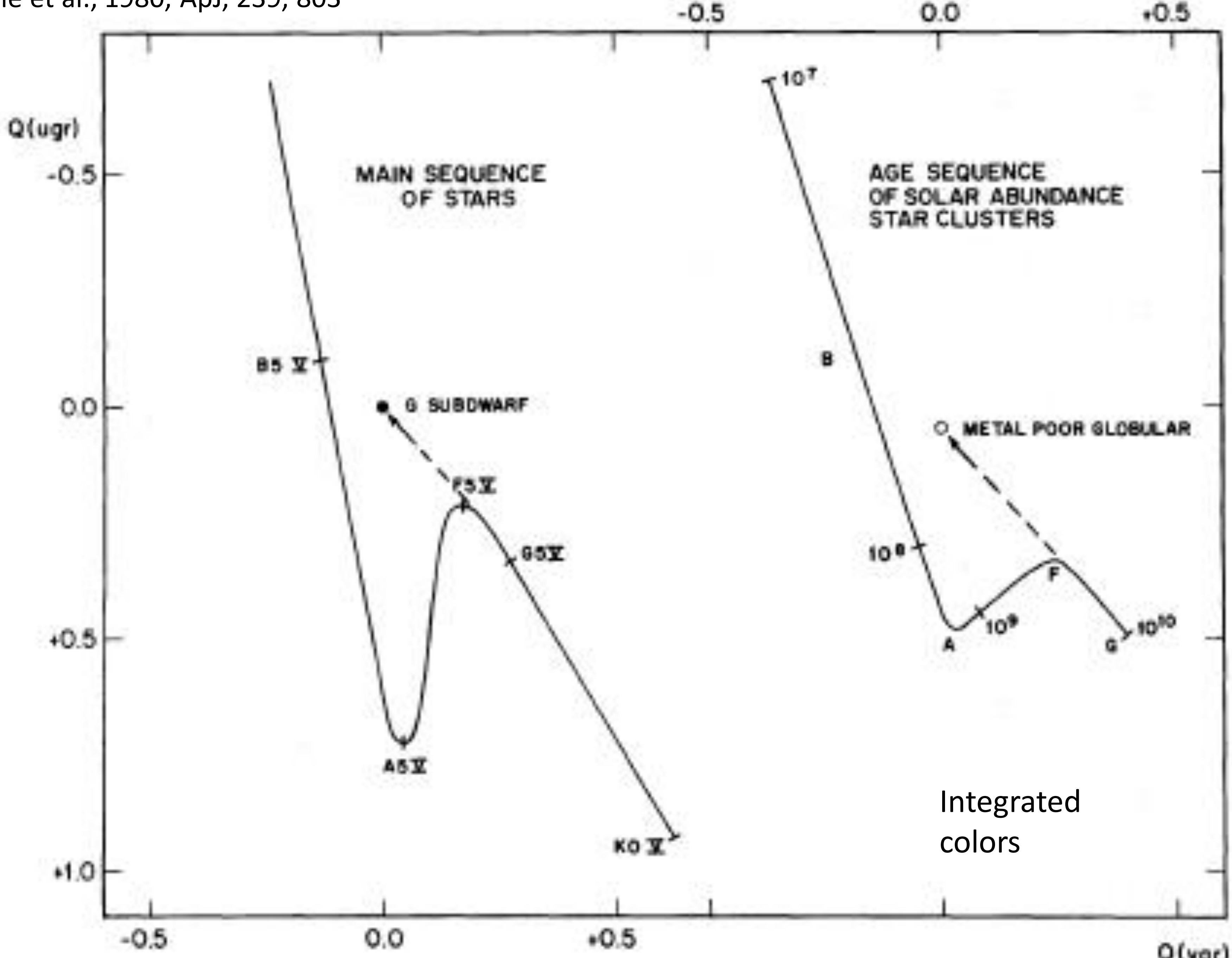
Classification of Star Clusters



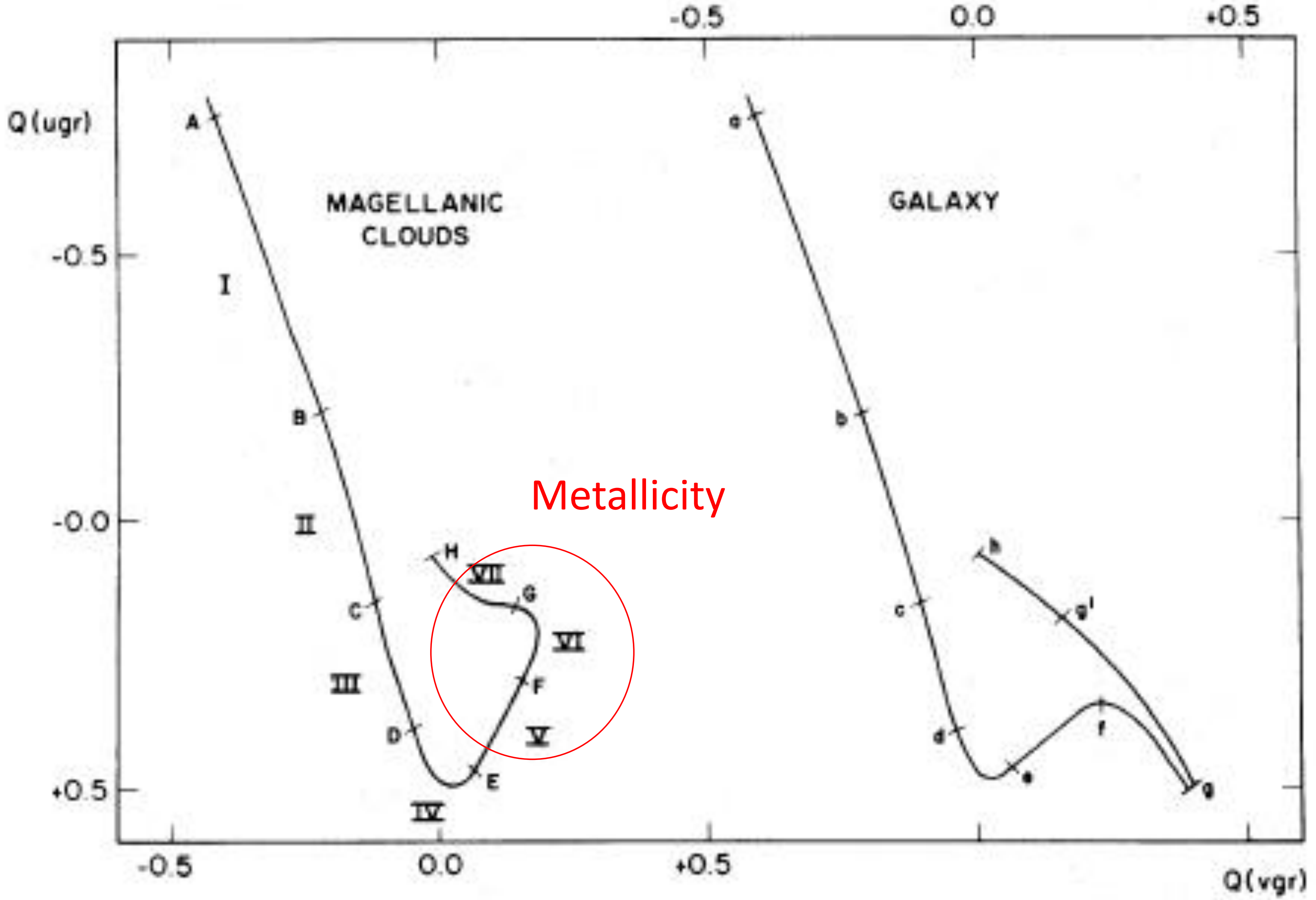
Reddening free indices

$$Q(ugr) = (u - g) - 1.08(g - r)$$
$$Q(vgr) = (v - g) - 0.68(g - r)$$

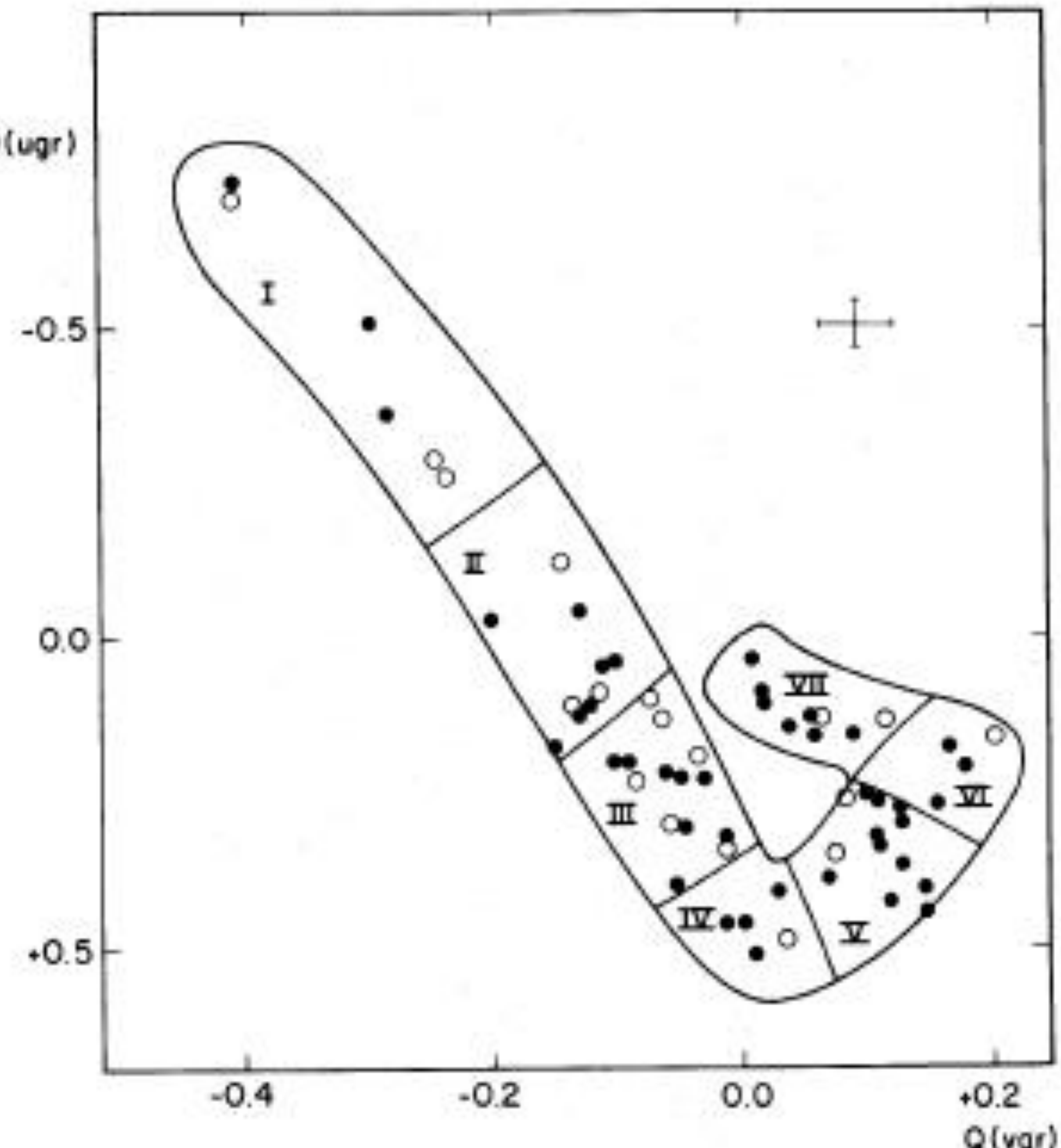
Searle et al., 1980, ApJ, 239, 803



Integrated colors



Searle et al., 1980, ApJ, 239, 803

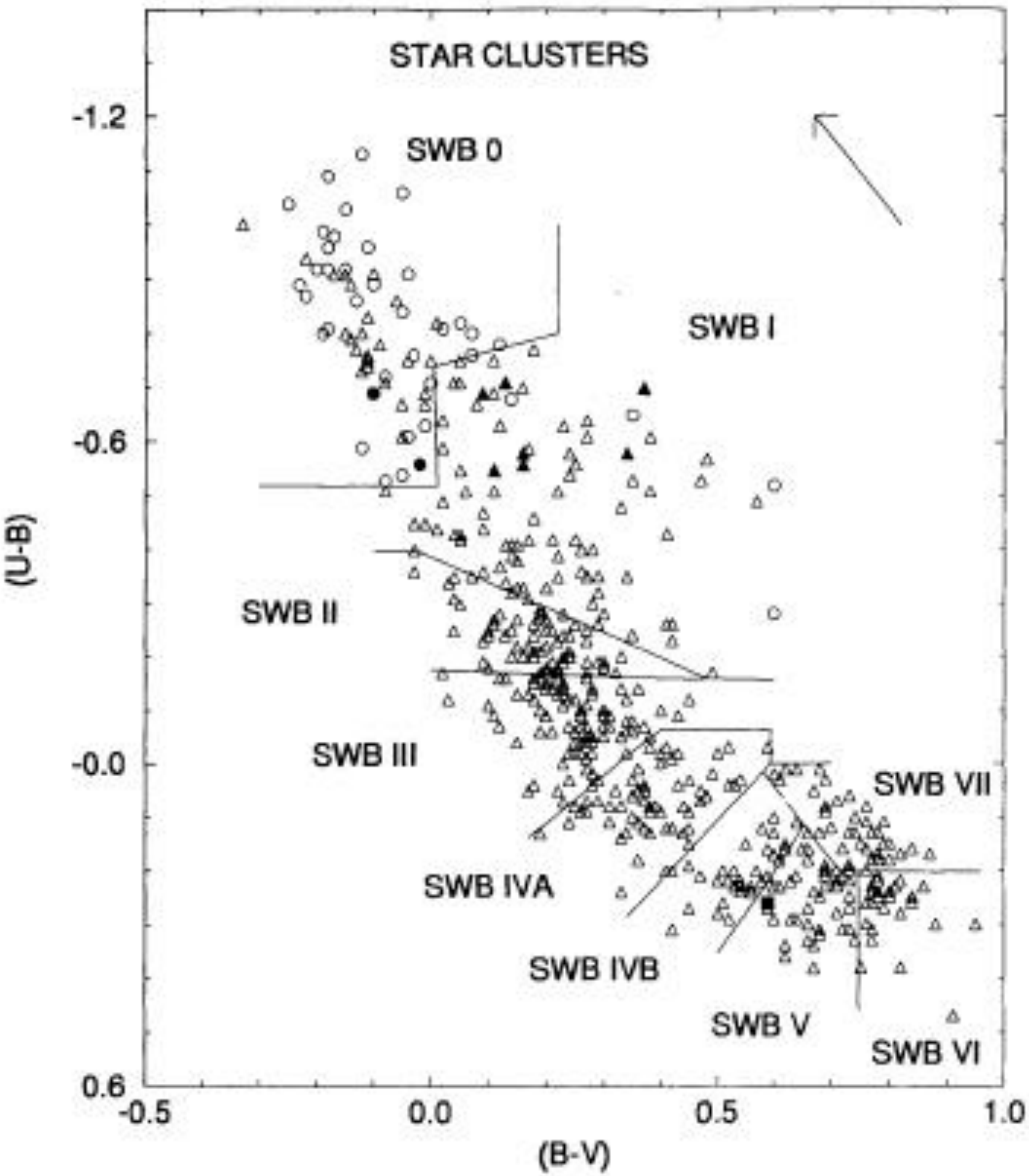


Seven “regions”

For LMC and SMC (open circles)

Age: I, II and III
Age and Metallicity: IV - VII

Searle et al., 1980, ApJ, 239, 803



Integrated colors of 624 Star Clusters in the LMC

Each "region" can be calibrated in terms of the age and the metallicity

Bica et al., 1996, ApJS, 102, 57

Group (SWB)	Age (Myr)	Clusters[a]	Associations[a]	Total	*M*	*m*	*M*/*m*	PA	x_c	y_c
0	0–10	61	77	138	6°.3	6°.3	1.00	140°	−0°.11	1°.14
I	10–30	89	41	130	6.7	6.3	1.00	150	−0.13	1.08
II	30–70	64	1	65	8.6	6.7	1.28	80	0.01	0.64
III	70–200	86	1	87	9.3	7.0	1.33	40	−0.40	0.48
IVA	200–400	62	0	62	11.6	8.0	1.45	10	−0.29	1.00
IVB	400–800	33	0	33	12.4	8.0	1.55	40	−0.76	−0.28
V	800–2000	41	0	41	13.3	10.5	1.27	40	−0.66	−0.55
VI	2000–5000	30	0	30	12.4	9.7	1.28	0	−0.47	−0.98
VII	5000–16000	38	0	38	17.0	10.7	1.59	40	−0.86	1.34
					(25.5[b])	(15.6[b])	(1.63[b])	(0[b])	(−0.64[b])	(1.16[b])
Total	0–16000	504	120	624	25.5[b]	15.6[b]	15.6[b]	0[b]	−0.28	0.68

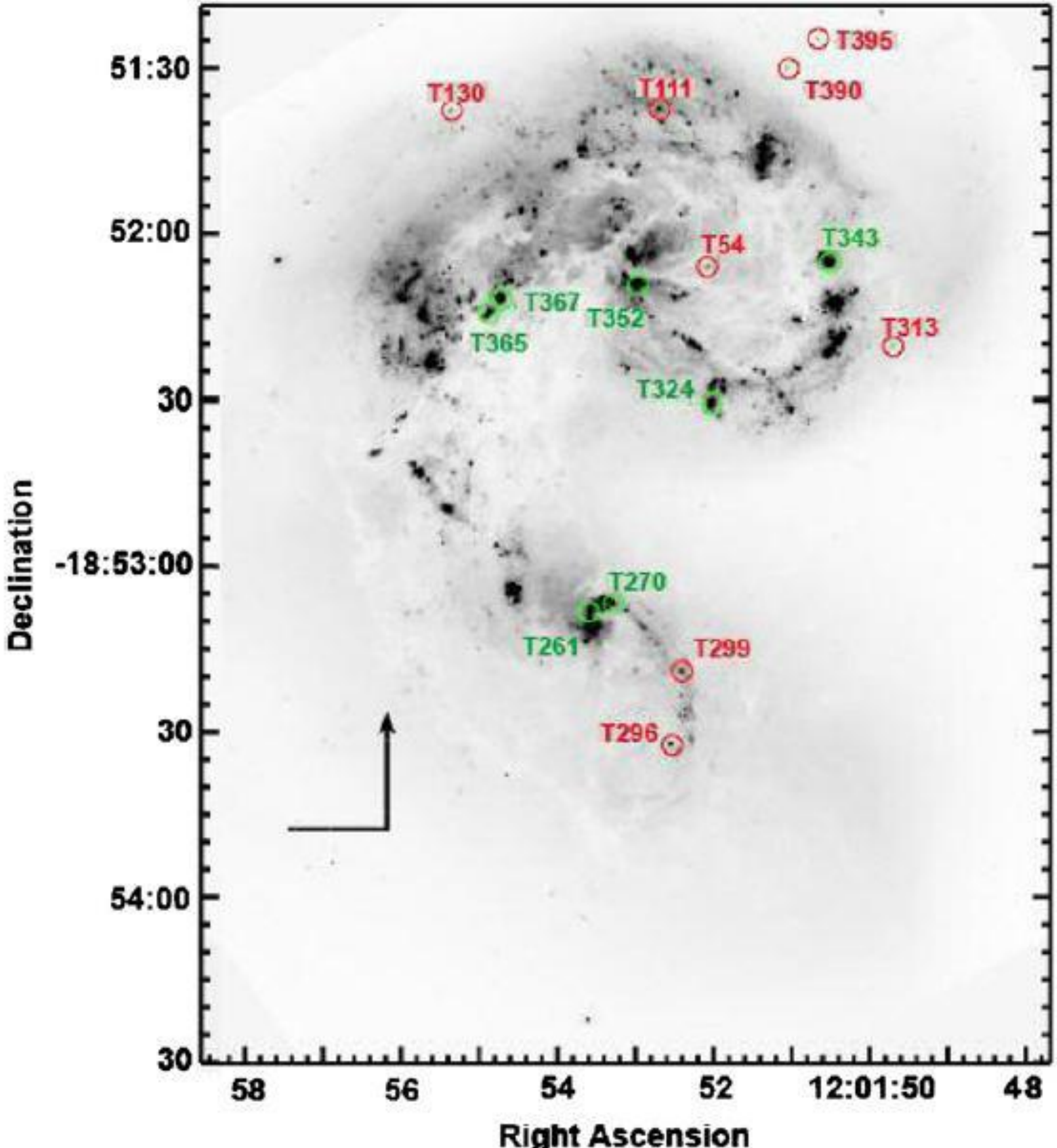
M and m, semimajor and semiminor axis

PA positional angle of M, North = 0°, East = 90°

Conclusions:

1. Age: continuous up to 16 Gyr
2. Star clusters do not dissipate because of the local rotation

Bica et al., 1996, ApJS, 102, 57



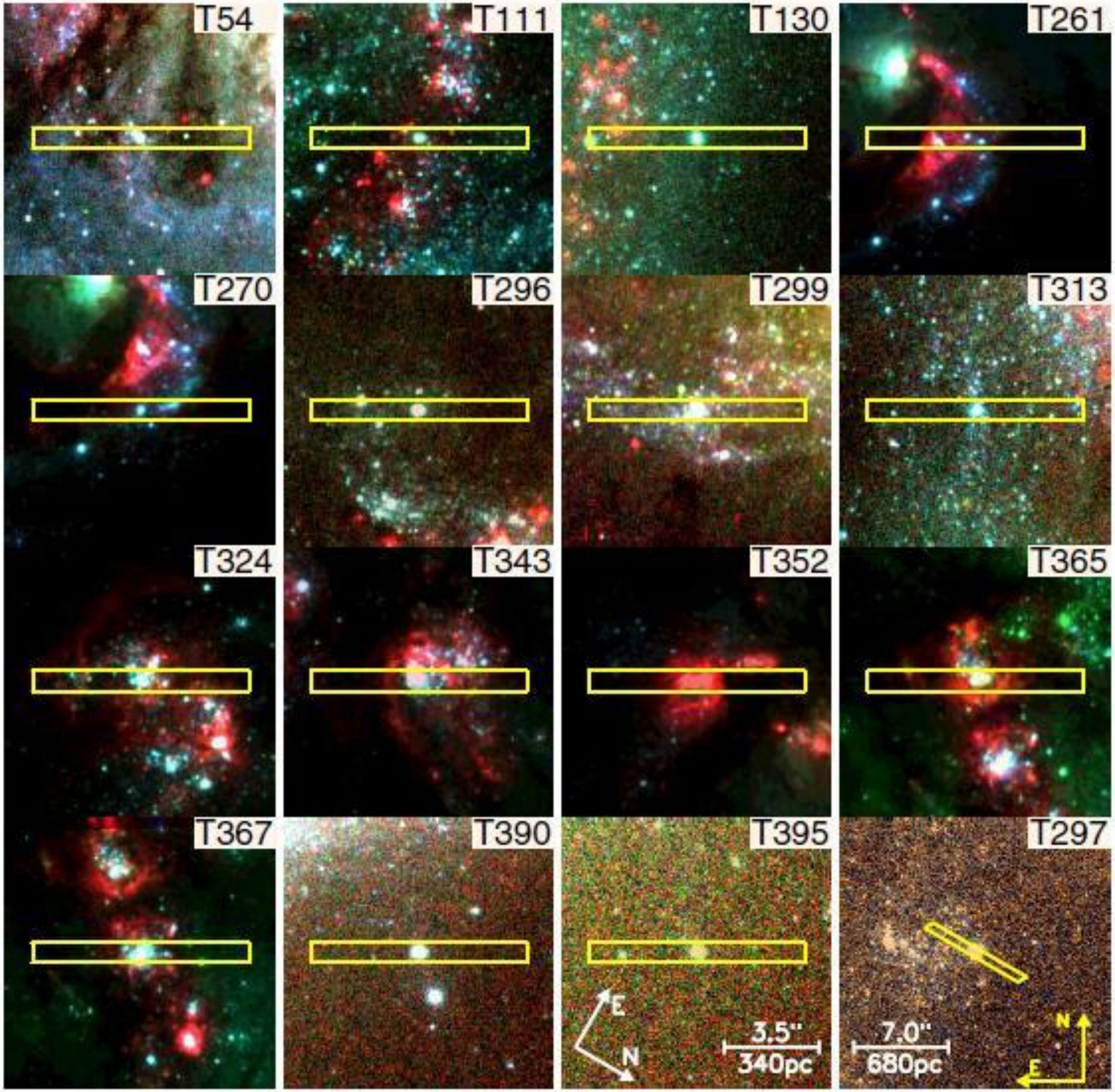
Star Clusters
in NGC 4038/9

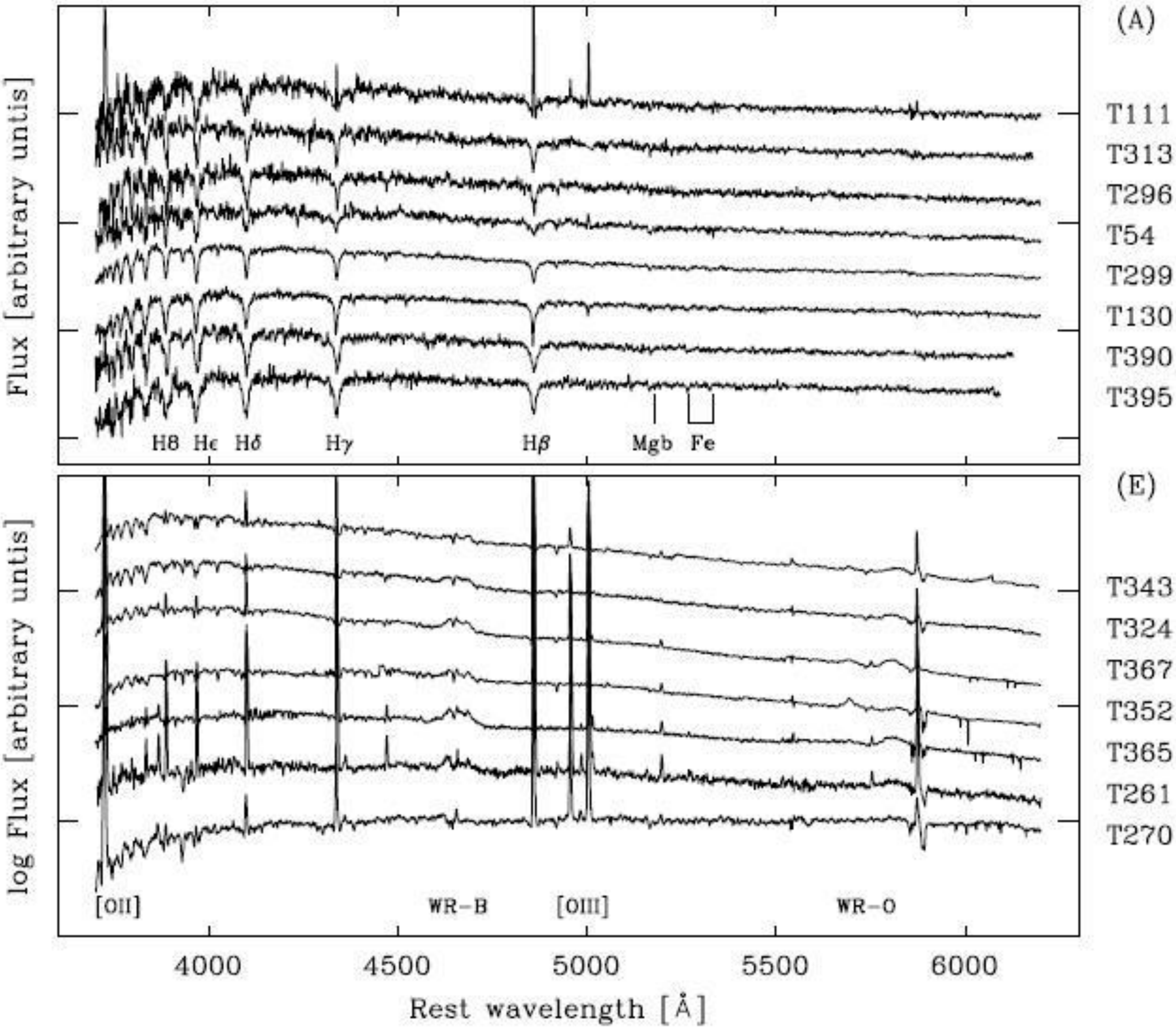
Antennae Galaxy

D = 20 Mpc

Bastian et al., 2009, ApJ, 701, 607

Positions of the slit





8 m
GEMINI

t = 4 h

ID	H + Hϵ[a] (Å)	K[a] (Å)	H8[a] (Å)	$H\gamma_A$[b] (Å)	Mgb5177[b] (Å)	Fe5270[b] (Å)	Fe5335[b] (Å)
T54	5.18 ± 0.19	0.75 ± 0.09	3.26 ± 0.19	4.12 ± 0.11	0.42 ± 0.07	0.90 ± 0.08	1.21 ± 0.12
T111	7.60 ± 0.29	0.91 ± 0.17	6.71 ± 0.30	7.02 ± 0.21	0.37 ± 0.11	1.02 ± 0.14	1.48 ± 0.22
T130	9.83 ± 0.31	0.76 ± 0.18	8.73 ± 0.31	8.65 ± 0.22	0.64 ± 0.12	1.05 ± 0.15	1.46 ± 0.22
T296	7.02 ± 0.19	0.77 ± 0.01	6.10 ± 0.20	6.57 ± 0.14	0.30 ± 0.08	0.96 ± 0.00	1.23 ± 0.06
T297	...	...	...	9.07 ± 0.41	0.73 ± 0.15	1.00 ± 0.07	1.36 ± 0.23
T299	5.88 ± 0.11	0.77 ± 0.06	4.70 ± 0.11	4.94 ± 0.08	0.20 ± 0.04	0.57 ± 0.06	0.67 ± 0.09
T313	7.48 ± 0.25	0.71 ± 0.04	7.00 ± 0.61	7.47 ± 0.40	0.44 ± 0.22	1.02 ± 0.27	1.51 ± 0.21
T390	9.43 ± 0.43	0.72 ± 0.25	8.35 ± 0.45	8.50 ± 0.29	0.45 ± 0.15	1.08 ± 0.19	1.46 ± 0.28
T395	11.20 ± 0.72	2.97 ± 0.41	9.94 ± 0.78	9.16 ± 0.51	0.77 ± 0.21	1.58 ± 0.26	1.86 ± 0.37

In addition: integrated colors from HST photometry

ID	A/E[a]	ΔR.A. (J2000)	ΔDecl. (J2000)	F336W (mag)	F435W (mag)	F550M (mag)	F814W (mag)	F658N (mag)	A_V (mag)	Z ($Z_\odot$)	Log(age) (year)
T54	0	12h01m52.s119	−18d52m07.s3	21.10	21.53	21.15	20.30	20.65	1.0	0.9 ± 0.1	6.9 ± 0.1
T111	0	12h01m53.s379	−18d51m39.s2	20.80	21.18	21.09	20.77	20.89	0.0	0.9 ± 0.3	7.9 ± 0.1
T130	0	12h01m55.s360	−18d51m38.s9	20.33	20.82	20.72	20.37	20.43	0.0	1.0 ± 0.1	8.4 ± 0.1
T261	1	12h01m53.s561	−18d53m07.s9	18.90	20.17	20.29	20.14	18.76	0.3	1.1 ± 0.2	<6.8
T270	1	12h01m53.s345	−18d53m07.s6	19.61	20.14	19.70	18.91	19.38	1.7	1.1 ± 0.2	<6.8
T296	0	12h01m52.s624	−18d53m33.s8	19.85	20.43	20.29	19.87	19.92	0.2	1.0 ± 0.0	7.9 ± 0.1
T297	0	12h02m00.s112	−18d54m33.s3	...	...	22.22[b]	21.60[b]	...	1.0	1.1 ± 0.1[c]	8.5 ± 0.2[c]
T299	0	12h01m52.s480	−18d53m20.s2	19.43	20.26	20.14	19.69	19.86	0.2	0.9 ± 0.1	7.35 ± 0.07
T313	0	12h01m49.s744	−18d52m21.s9	21.29	21.88	21.80	21.35	21.59	0.2	1.0 ± 0.1	7.8 ± 0.1
T324	2	12h01m52.s085	−18d52m31.s9	17.76	19.01	18.97	18.74	18.40	0.6	1.2 ± 0.2	6.5–6.8[d]
T343	2	12h01m50.s537	−18d52m06.s6	17.23	18.43	18.44	18.30	17.73	0.4	1.3 ± 0.2	6.5–6.8[d]
T352	1	12h01m53.s022	−18d52m10.s6	16.33	17.69	17.54	17.57	17.01	0.3	1.3 ± 0.2	<6.8
T365	2	12h01m54.s928	−18d52m15.s4	17.78	19.04	18.92	18.66	18.48	0.7	1.1 ± 0.2	6.5–6.8[d]
T367	2	12h01m54.s749	−18d52m12.s9	16.78	18.27	18.45	18.51	17.78	0.0	1.3 ± 0.2	6.5–6.8[d]
T390	0	12h01m51.s076	−18d51m31.s5	21.37	21.50	21.35	20.94	21.15	0.0	1.1 ± 0.4	8.3 ± 0.1
T395	0	12h01m50.s681	−18d51m26.s0	21.78	21.77	21.62	21.19	21.34	0.1	1.1 ± 0.2	8.8 ± 0.1

Determination of the extinction, metallicity and age possible

ID	Agreement[a]	cz(H I)[b] (km s^{-1})	czhel (km s^{-1})	deltcz (km s^{-1})	log(Mass) $\mathcal{M}_\odot$	R_{eff} (pc)
T54	0	1700	1697 ± 54	−3	4.8 ± 0.3	3.7
T111	0	1560	1595 ± 115	+35	5.3 ± 0.3	6.7
T130	0	1565	1617 ± 61	+52	5.7 ± 0.3	6.0
T261	0	1670	1621 ± 13	−49	4.6 ± 0.3	...
T270	0	1715	1711 ± 19	−4	5.4 ± 0.3	9.3
T296	0	1755	1733 ± 35	−22	5.6 ± 0.3	4.0
T297	1	1675	1553 ± 41	−122	5.2 ± 0.3	...
T299	0	1795:[c]	1810 ± 38	+15:	5.4 ± 0.3	8.4
T313	0	1695	1657 ± 33	−38	5.0 ± 0.3	12.8
T324	0	1690	1679 ± 24	−11	5.2 ± 0.3	7.7
T343	0	1630	1613 ± 16	−17	5.4 ± 0.3	8.8
T352	0	1640	1679 ± 24	+39	5.7 ± 0.3	...
T365	0	1630	1572 ± 15	−58	5.3 ± 0.3	4.3
T367	0	1630	1657 ± 13	+26	5.2 ± 0.3	6.6
T390	1	1530:	1689 ± 35	+159:	5.4 ± 0.3	8.9
T395	1	1580:	1727 ± 42	+147:	5.3 ± 0.3	7.5

R_V

Bastian et al., 2009, ApJ, 701, 607