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
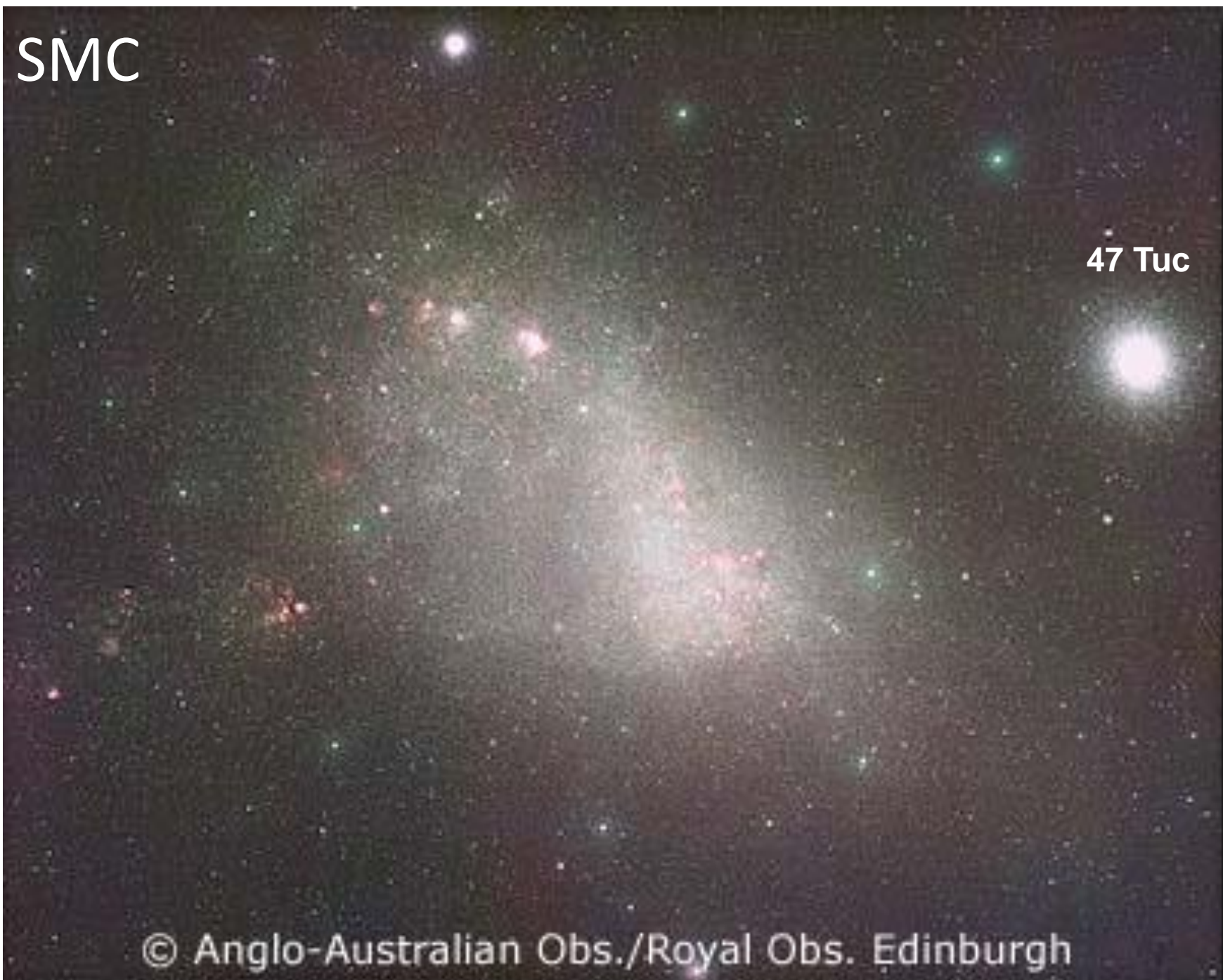
LMC

6 Degrees on the sky

© Anglo-Australian Observatory/Royal Observatory, Edinburgh

SMC

5.4 Degrees on the Sky

47 Tuc

© Anglo-Australian Obs./Royal Obs. Edinburgh

4 Arc minutes

© Anglo-Australian Observatory

30 Dor:

Star cluster in the LMC

4850 listed star clusters of the LMC in Bitsakis et al., 2017, ApJ, 845, 56

2741 listed star clusters in the SMC and the Magellanic Bridge in Bica et al., 2020, AJ, 159, 82

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 (MW)
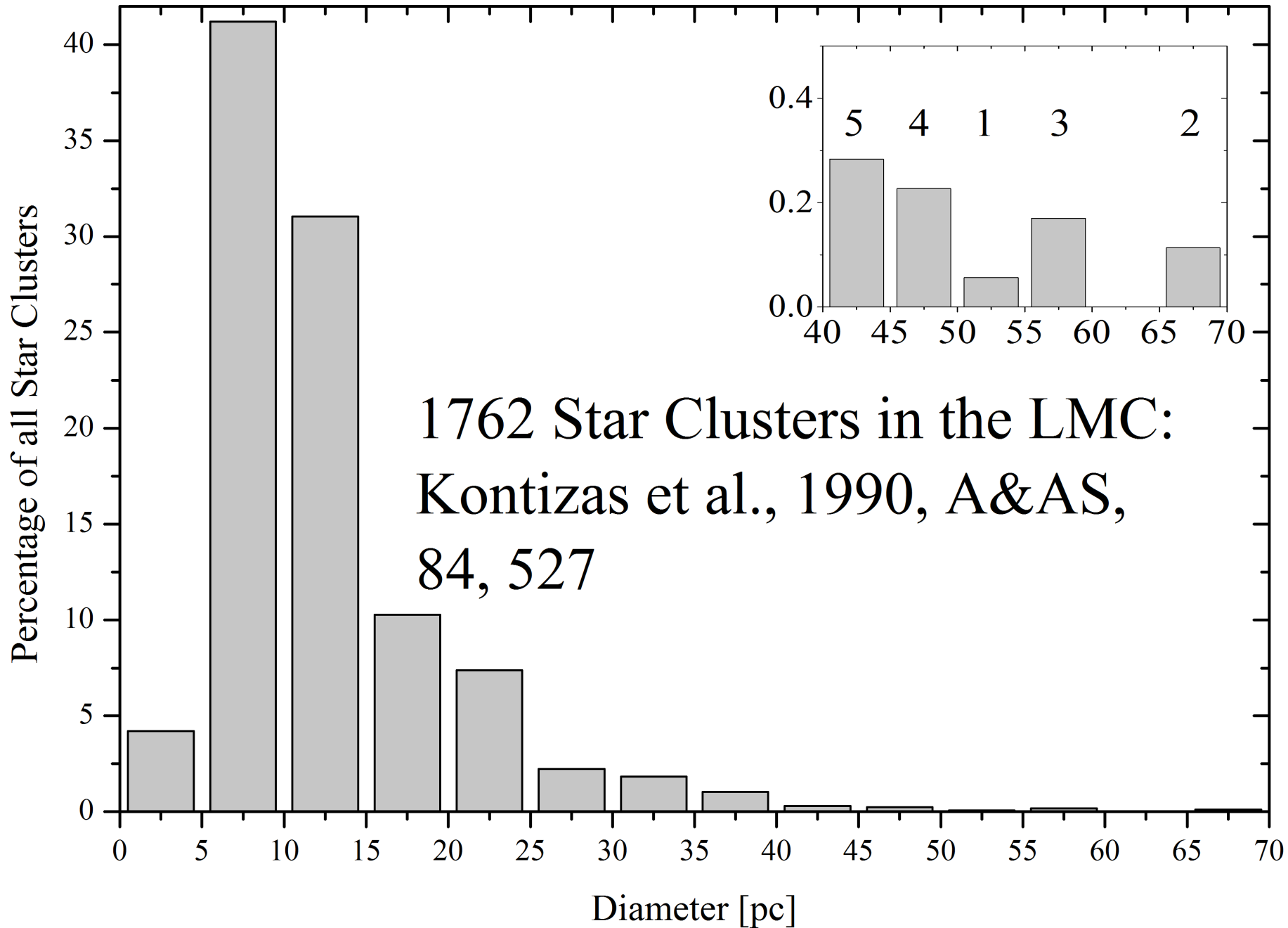
Distance and Reddening

- 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 Milky Way (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_{star}	V_{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

Diameters comparable to the MW

1762 Star Clusters in the LMC: Kontizas et al., 1990, A&AS, 84, 527

- 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, Gaia should get better data
  6. Star clusters are most suitable to perform "statistical investigations"

Classification of Star Clusters
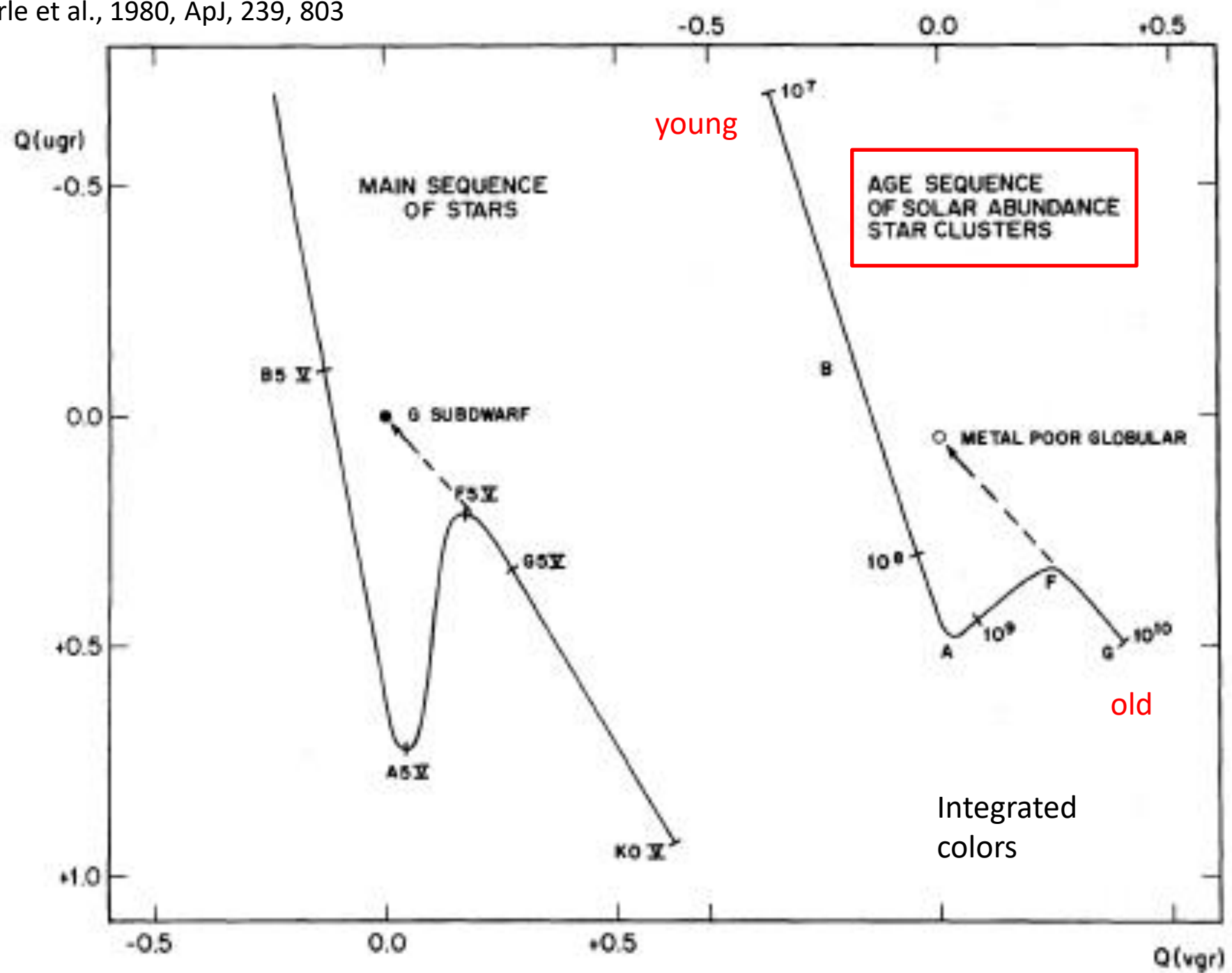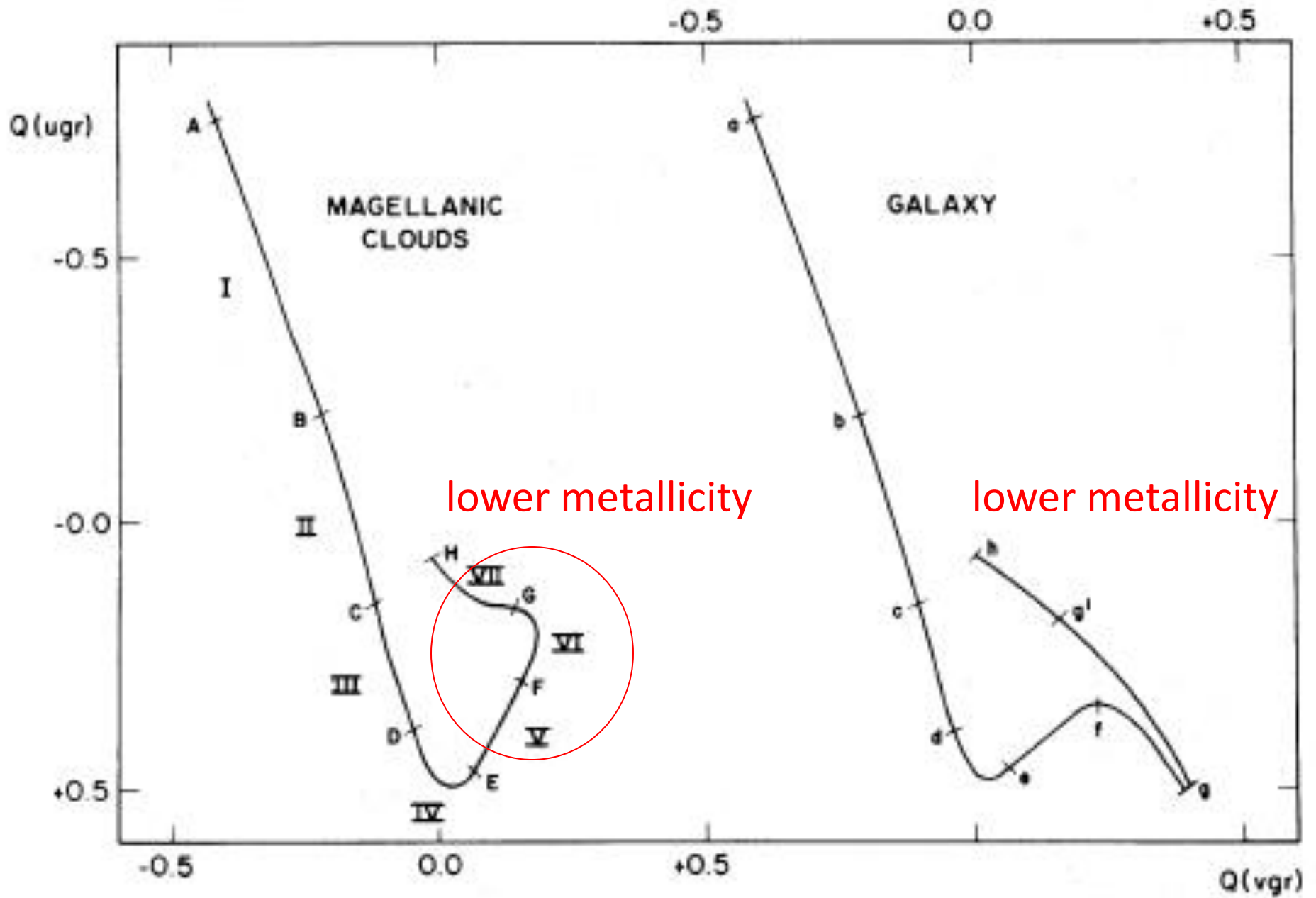

uvgr - Thuan and Gunn - 1976
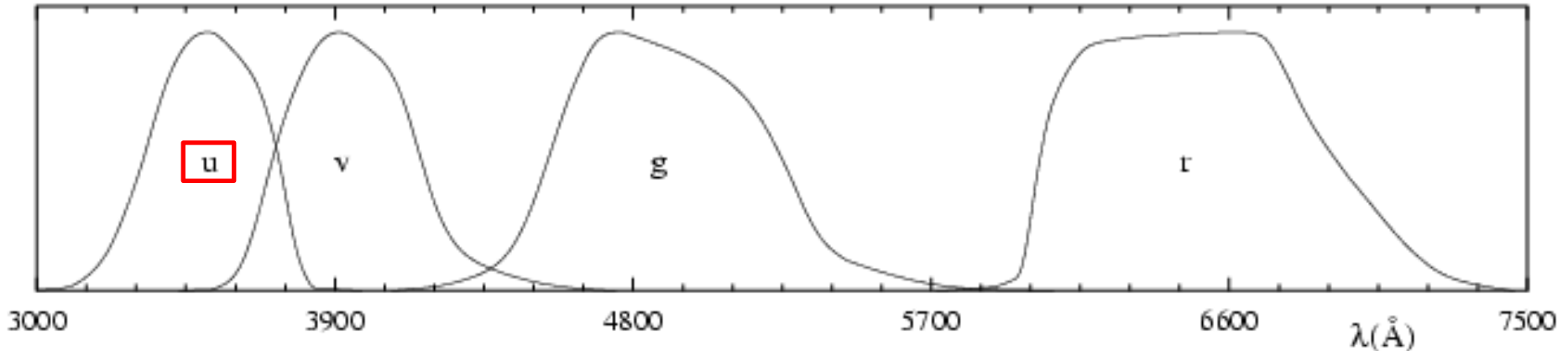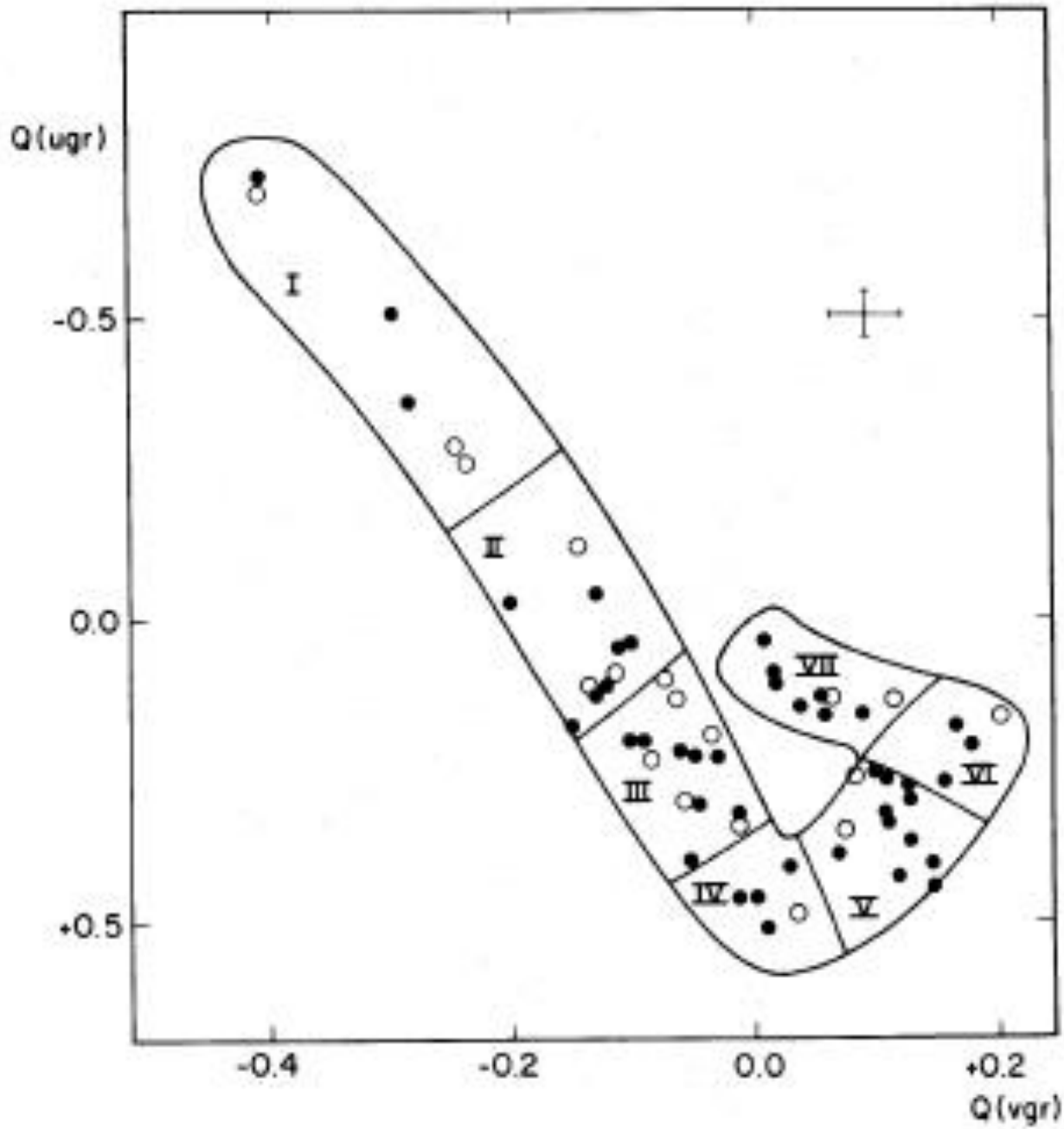
Reddening free indices

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

You need integrated photometric observations with these four filters to classify star clusters in the MCs. Also works with other photometric systems, but you need a filter in the U region.

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

Searle et al., 1980, ApJ, 239, 803
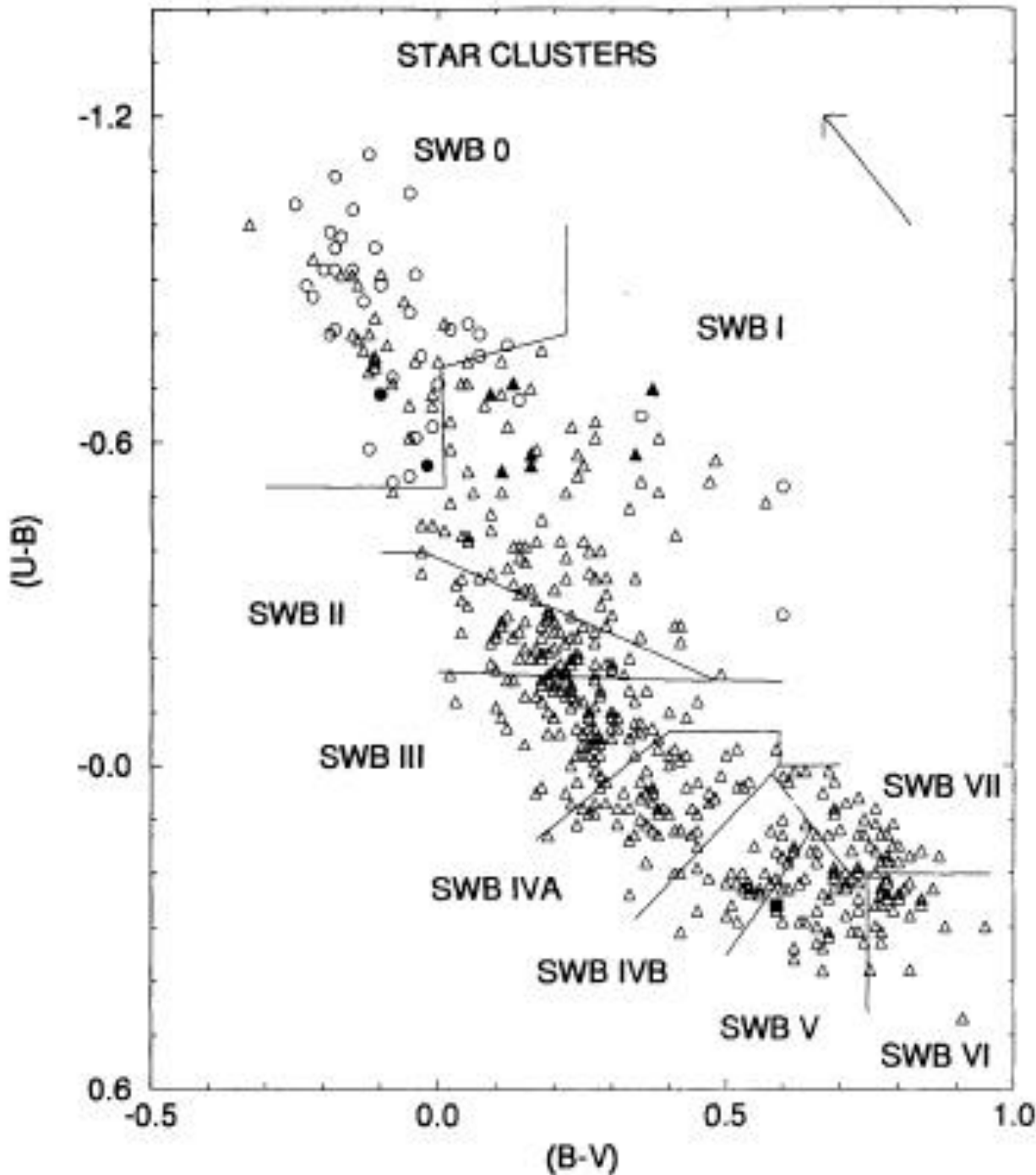
Seven "regions"

For LMC (full circles) 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

Here is an example of Johnson UBV photometry and not Gunn uvgr

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 = 0º, East = 90º

Conclusions:

1. Age: continuous up to 16 Gyr
2. Star clusters do not dissipate because of the local rotation
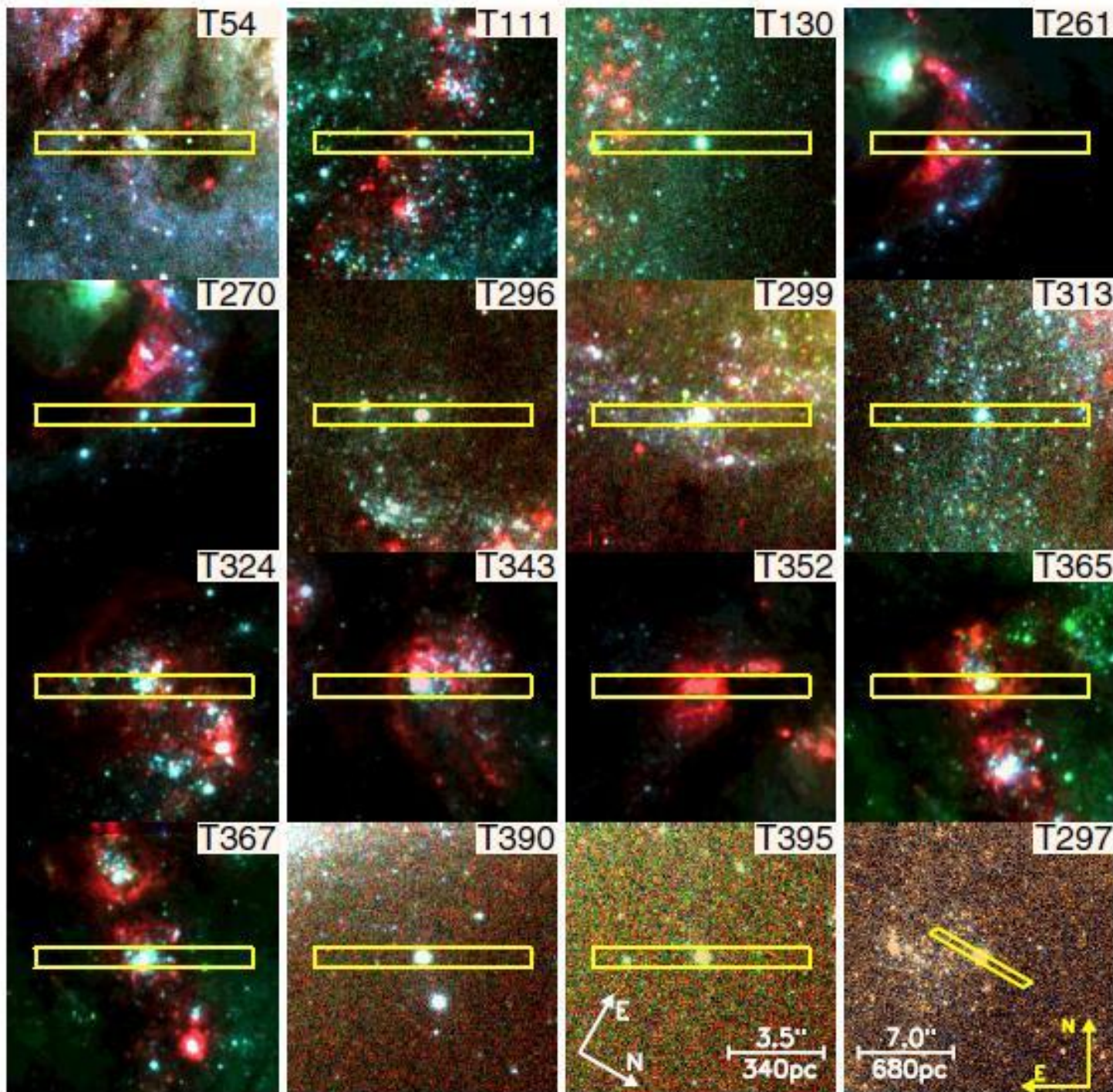
Bica et al., 1996, ApJS, 102, 57
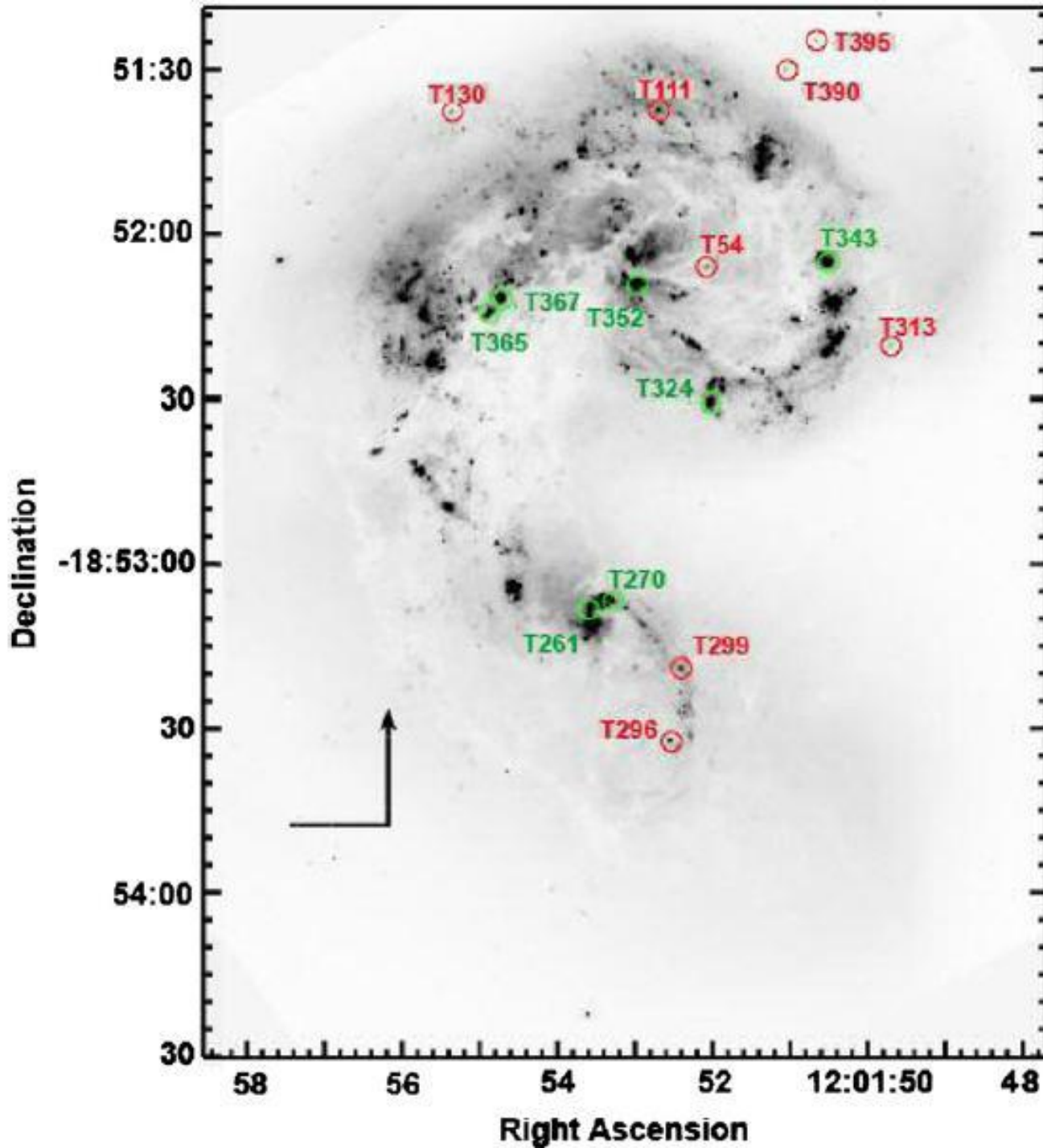
Star Clusters
in NGC 4038/9

Antennae Galaxy

D = 20 Mpc

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

Positions of the slit
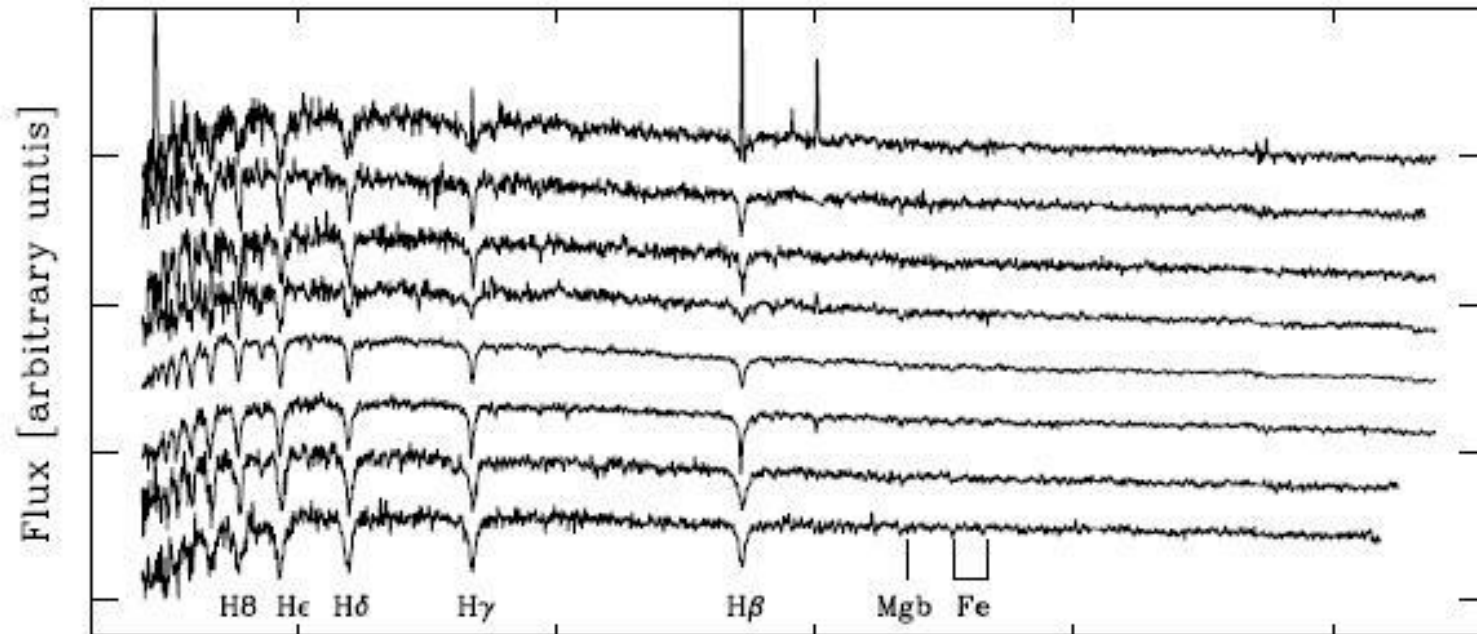
(A) 8m telescope GEMINI

T111
T313
T296
T54
T299   integration
T130   time 4h for
T390   each
T395   spectrum

H8 Hε Hδ   Hγ   Hβ   Mgb Fe
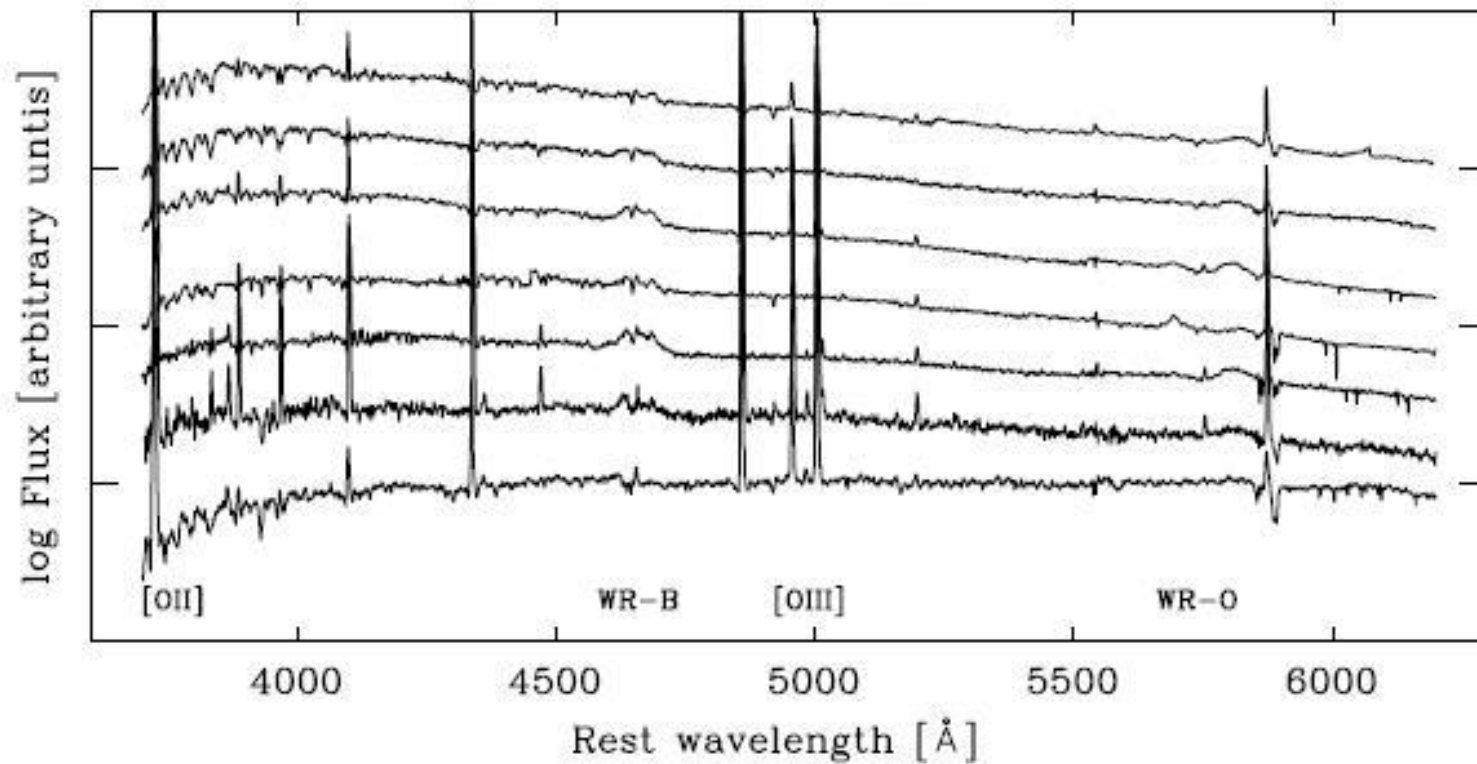
(E)

T343   very young
T324   because
T367   emission is
T352   visible
T365   ⇒ WR, O or
T261   B-type stars
T270   still present

[OII]   WR−B   [OIII]   WR−O

Flux [arbitrary untis]

log Flux [arbitrary untis]

Rest wavelength [Å]

ID	H + Hε[a] (Å)	K[a] (Å)	H8[a] (Å)	Hγ$_A$[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	$12^h01^m52^s.119$	$-18^d52^m07^s.3$	21.10	21.53	21.15	20.30	20.65	1.0	0.9 ± 0.1	6.9 ± 0.1
T111	0	$12^h01^m53^s.379$	$-18^d51^m39^s.2$	20.80	21.18	21.09	20.77	20.89	0.0	0.9 ± 0.3	7.9 ± 0.1
T130	0	$12^h01^m55^s.360$	$-18^d51^m38^s.9$	20.33	20.82	20.72	20.37	20.43	0.0	1.0 ± 0.1	8.4 ± 0.1
T261	1	$12^h01^m53^s.561$	$-18^d53^m07^s.9$	18.90	20.17	20.29	20.14	18.76	0.3	1.1 ± 0.2	<6.8
T270	1	$12^h01^m53^s.345$	$-18^d53^m07^s.6$	19.61	20.14	19.70	18.91	19.38	1.7	1.1 ± 0.2	<6.8
T296	0	$12^h01^m52^s.624$	$-18^d53^m33^s.8$	19.85	20.43	20.29	19.87	19.92	0.2	1.0 ± 0.0	7.9 ± 0.1
T297	0	$12^h02^m00^s.112$	$-18^d54^m33^s.3$	$\cdots$	$\cdots$	22.22[b]	21.60[b]	$\cdots$	1.0	1.1 ± 0.1[c]	8.5 ± 0.2[c]
T299	0	$12^h01^m52^s.480$	$-18^d53^m20^s.2$	19.43	20.26	20.14	19.69	19.86	0.2	0.9 ± 0.1	7.35 ± 0.07
T313	0	$12^h01^m49^s.744$	$-18^d52^m21^s.9$	21.29	21.88	21.80	21.35	21.59	0.2	1.0 ± 0.1	7.8 ± 0.1
T324	2	$12^h01^m52^s.085$	$-18^d52^m31^s.9$	17.76	19.01	18.97	18.74	18.40	0.6	1.2 ± 0.2	6.5–6.8[d]
T343	2	$12^h01^m50^s.537$	$-18^d52^m06^s.6$	17.23	18.43	18.44	18.30	17.73	0.4	1.3 ± 0.2	6.5–6.8[d]
T352	1	$12^h01^m53^s.022$	$-18^d52^m10^s.6$	16.33	17.69	17.54	17.57	17.01	0.3	1.3 ± 0.2	<6.8
T365	2	$12^h01^m54^s.928$	$-18^d52^m15^s.4$	17.78	19.04	18.92	18.66	18.48	0.7	1.1 ± 0.2	6.5–6.8[d]
T367	2	$12^h01^m54^s.749$	$-18^d52^m12^s.9$	16.78	18.27	18.45	18.51	17.78	0.0	1.3 ± 0.2	6.5–6.8[d]
T390	0	$12^h01^m51^s.076$	$-18^d51^m31^s.5$	21.37	21.50	21.35	20.94	21.15	0.0	1.1 ± 0.4	8.3 ± 0.1
T395	0	$12^h01^m50^s.681$	$-18^d51^m26^s.0$	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]	$cz(\text{H\,{\small I}})$[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

czhel = R_V … radial velocity

With "deltcz" you can measure the kinematics of the host galaxy

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