

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. M31 (Andromeda Galaxy), 1200 GCLs; Galleti et al., 2004, A6A, 416, 917
- Review: Brodie & Strader, 2006, ARA&A, 44, 193

6 Degrees on the sky

LMC

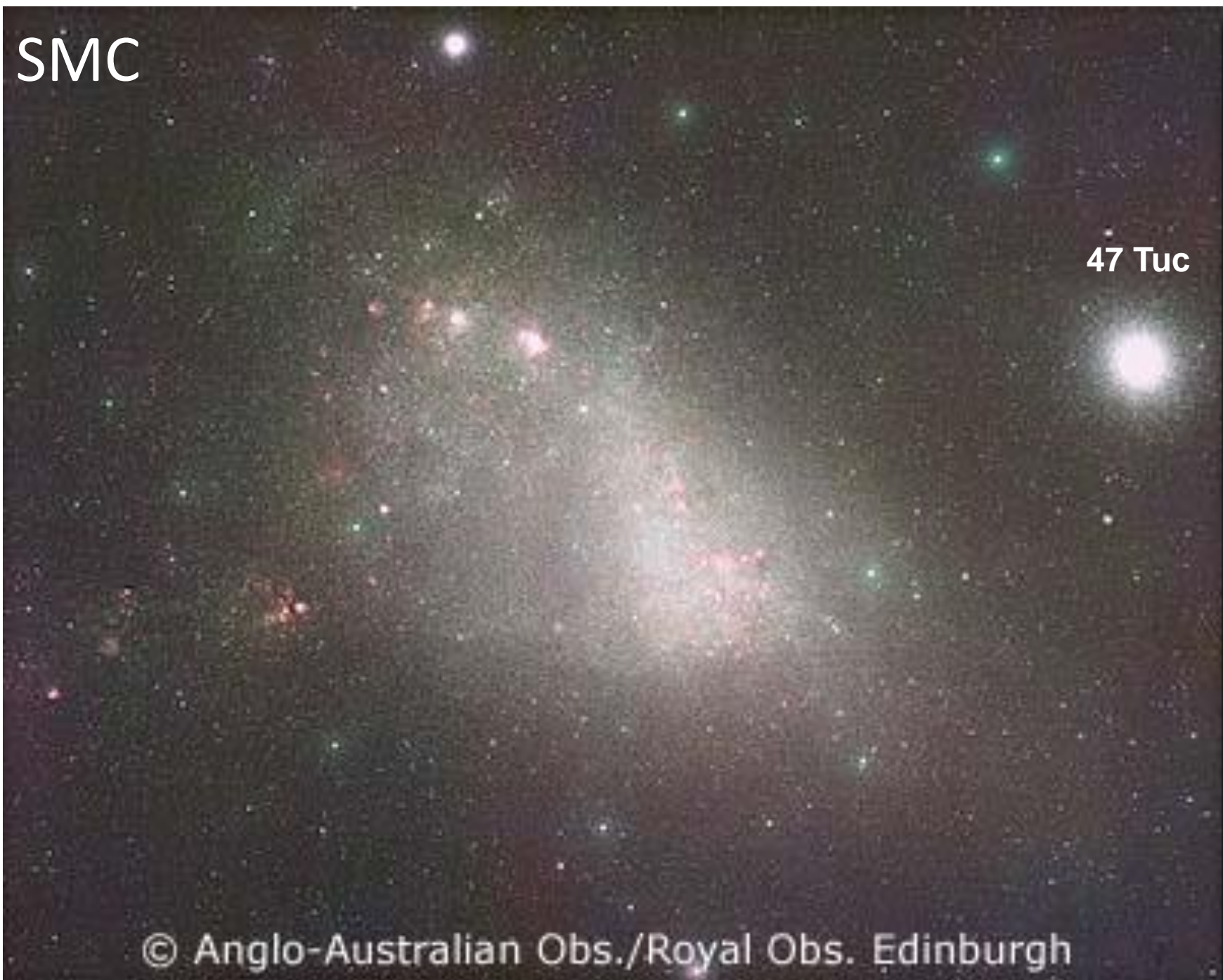


SMC

47 Tuc

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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

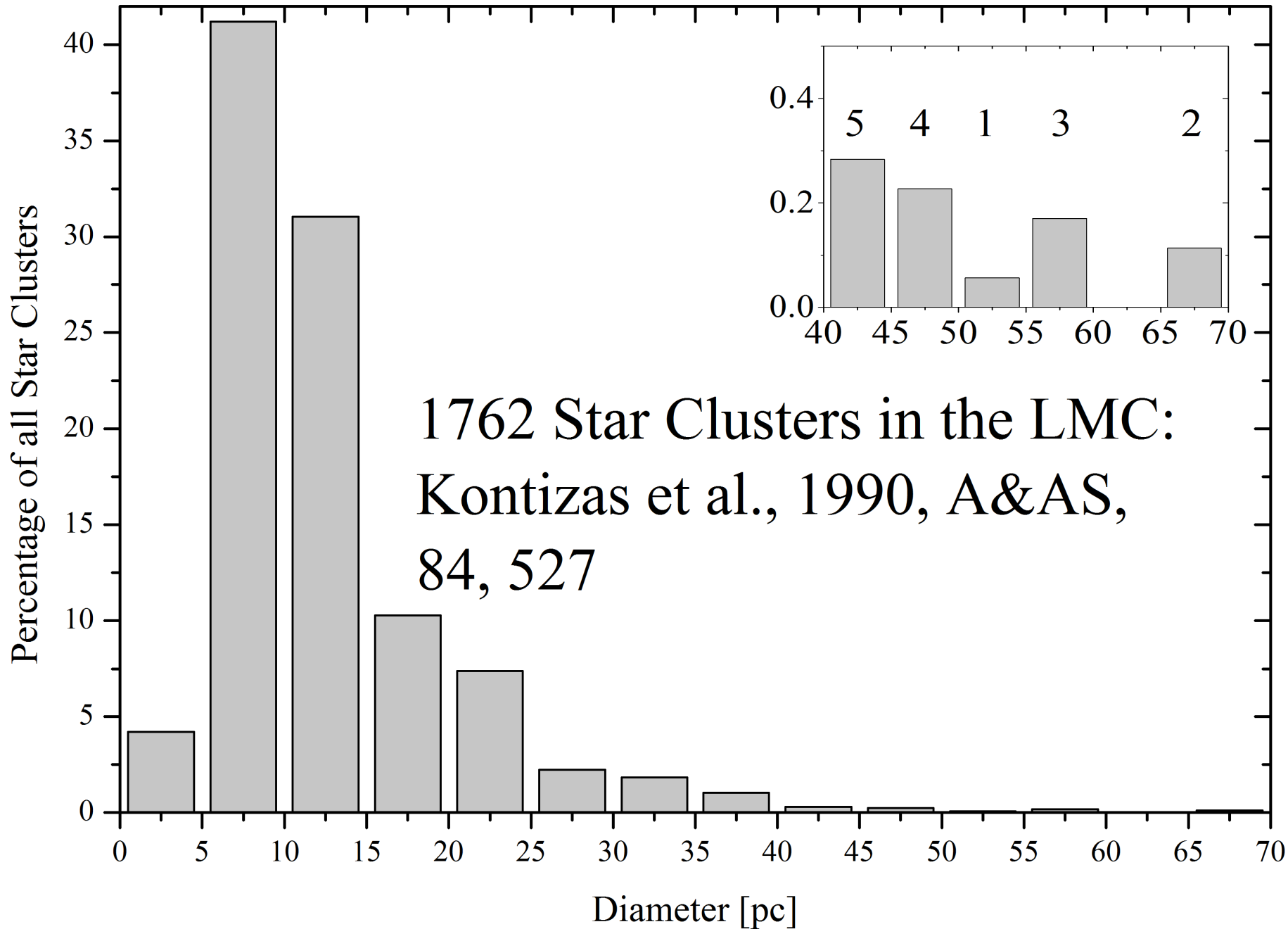
Distance and Reddening

- 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: $-2 < [\text{Fe}/\text{H}] < -0.3$ dex
- Total masses about 20 times lower than in the MW
- Global magnetic field lower than in the MW

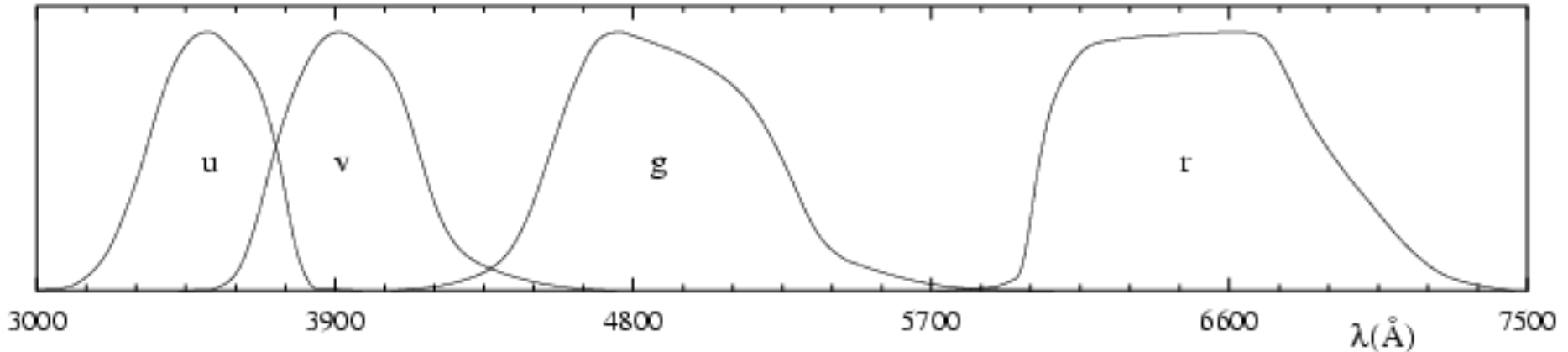
	Cluster	SWB class	R (arcsec)	N_{star}	V_{TO} (mag)	age (Myr)
LMC	KMHK265	...	30	303	16.5	50 ÷ 100
	NGC 1902	II	40	440	17	100 ÷ 150
	KMHK264	...	30	7 pc 241	17.5	150 ÷ 200
	NGC 1777	IV B	25 ÷ 70	804	19.5	700 ÷ 800
	IC 2146	V	60	2023	20.25	1200 ÷ 1500
	NGC 2155	VI	16 ÷ 50	1085	20.5	1500 ÷ 2000
SMC	NGC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



- 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

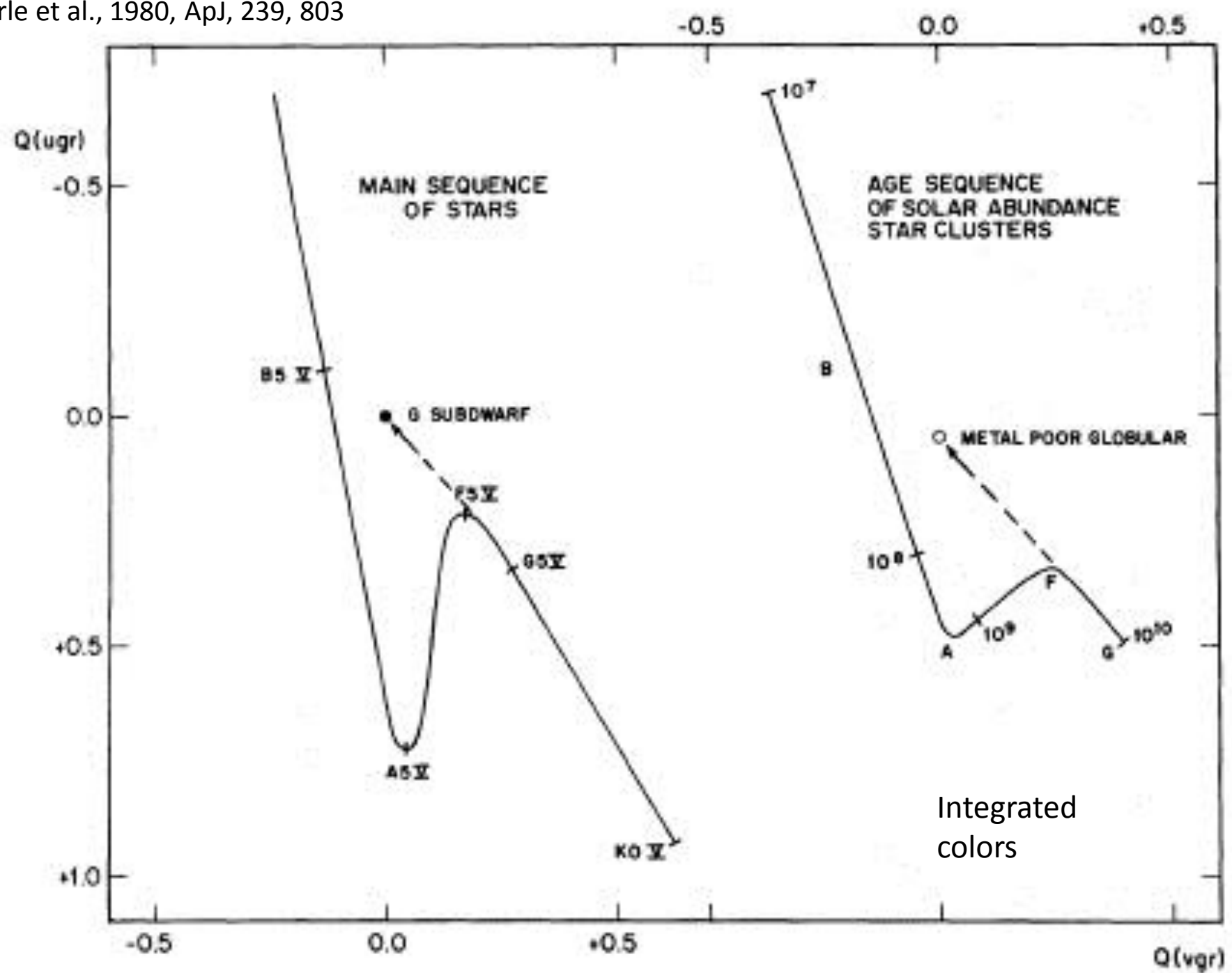
uvgr - Thuan and Gunn - 1976

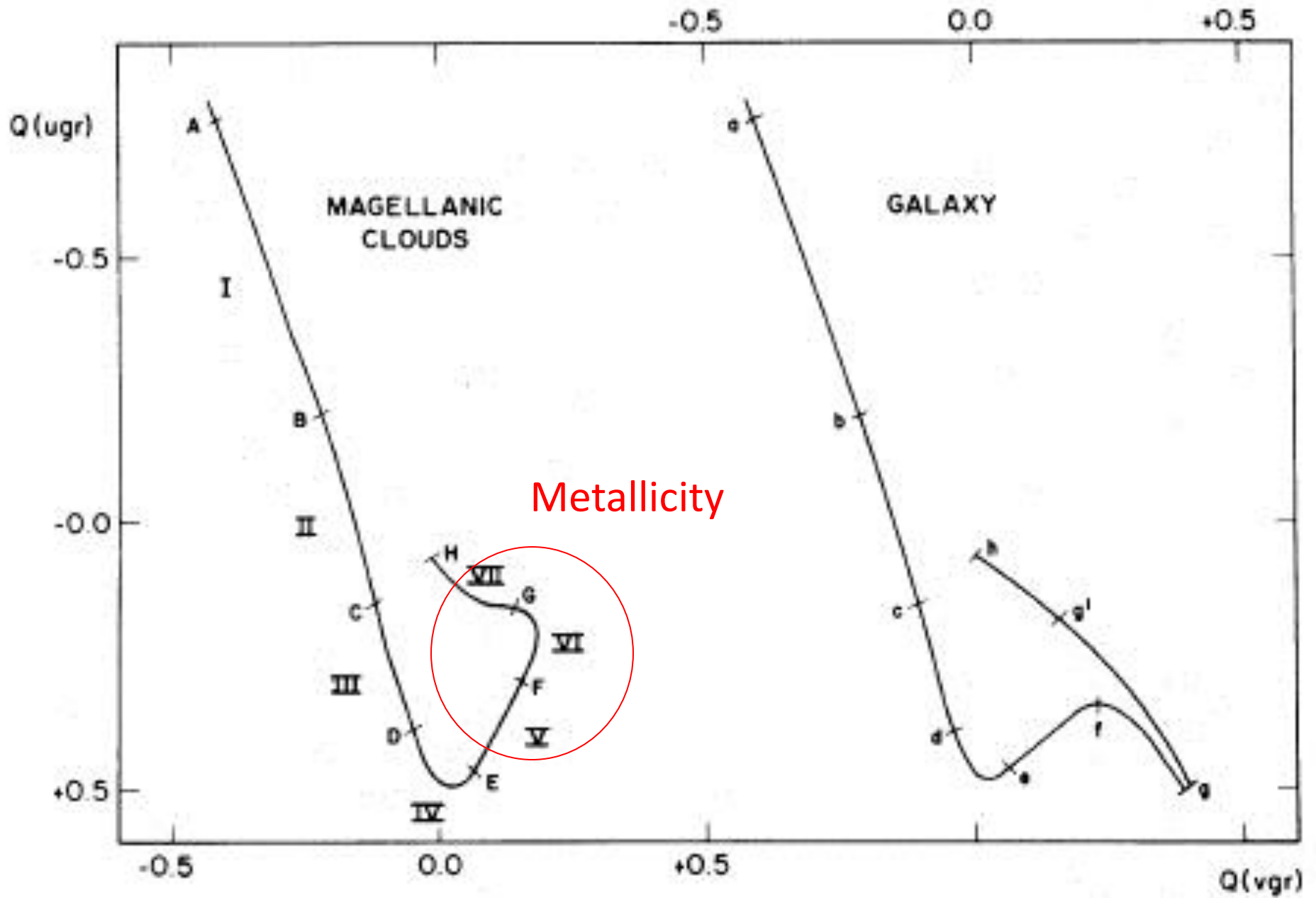


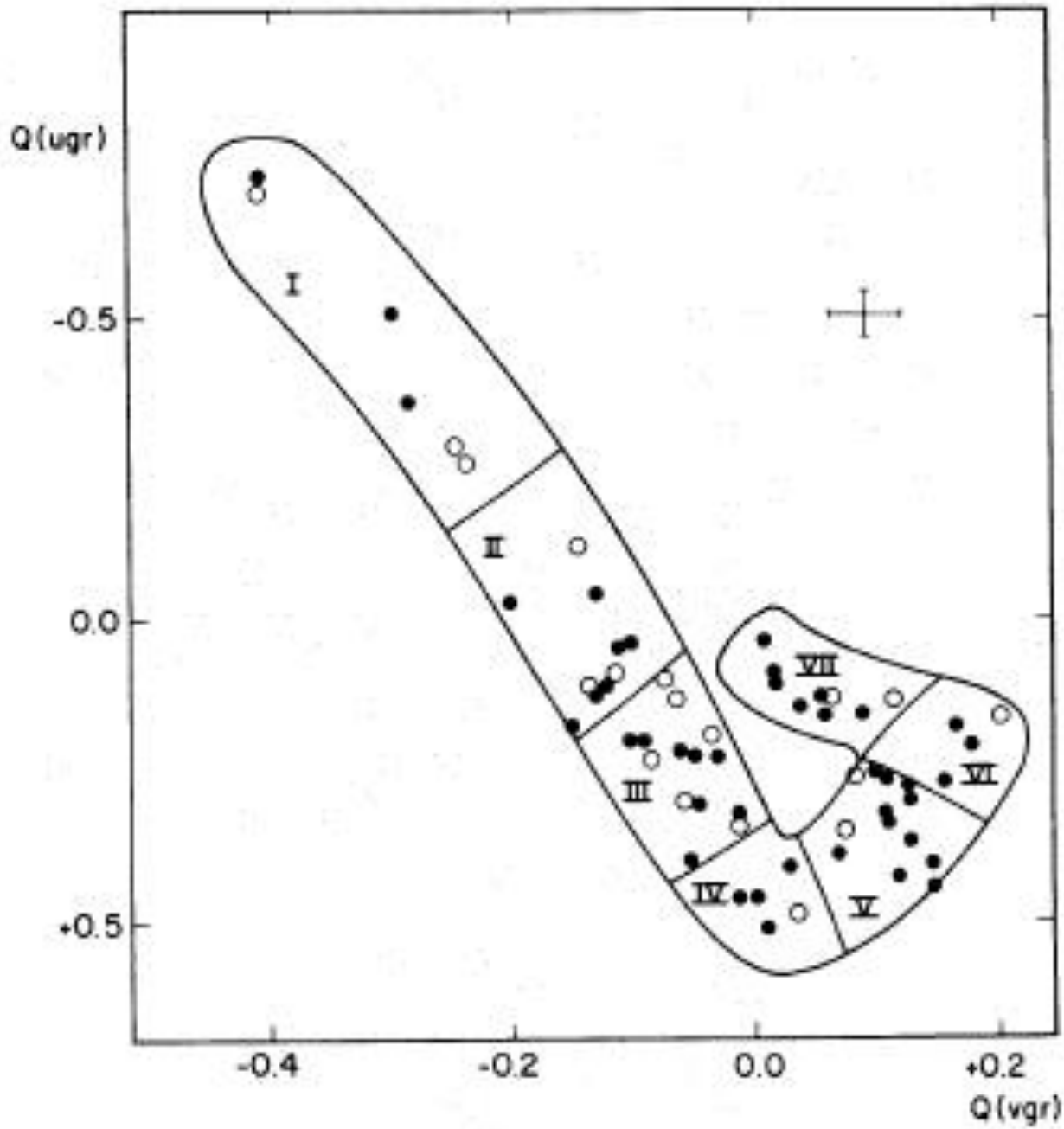
Reddening free
indices

$$Q(ugr) = (u - g) - 1.08(g - r)$$

$$Q(vgr) = (v - g) - 0.68(g - r)$$







Seven “regions”

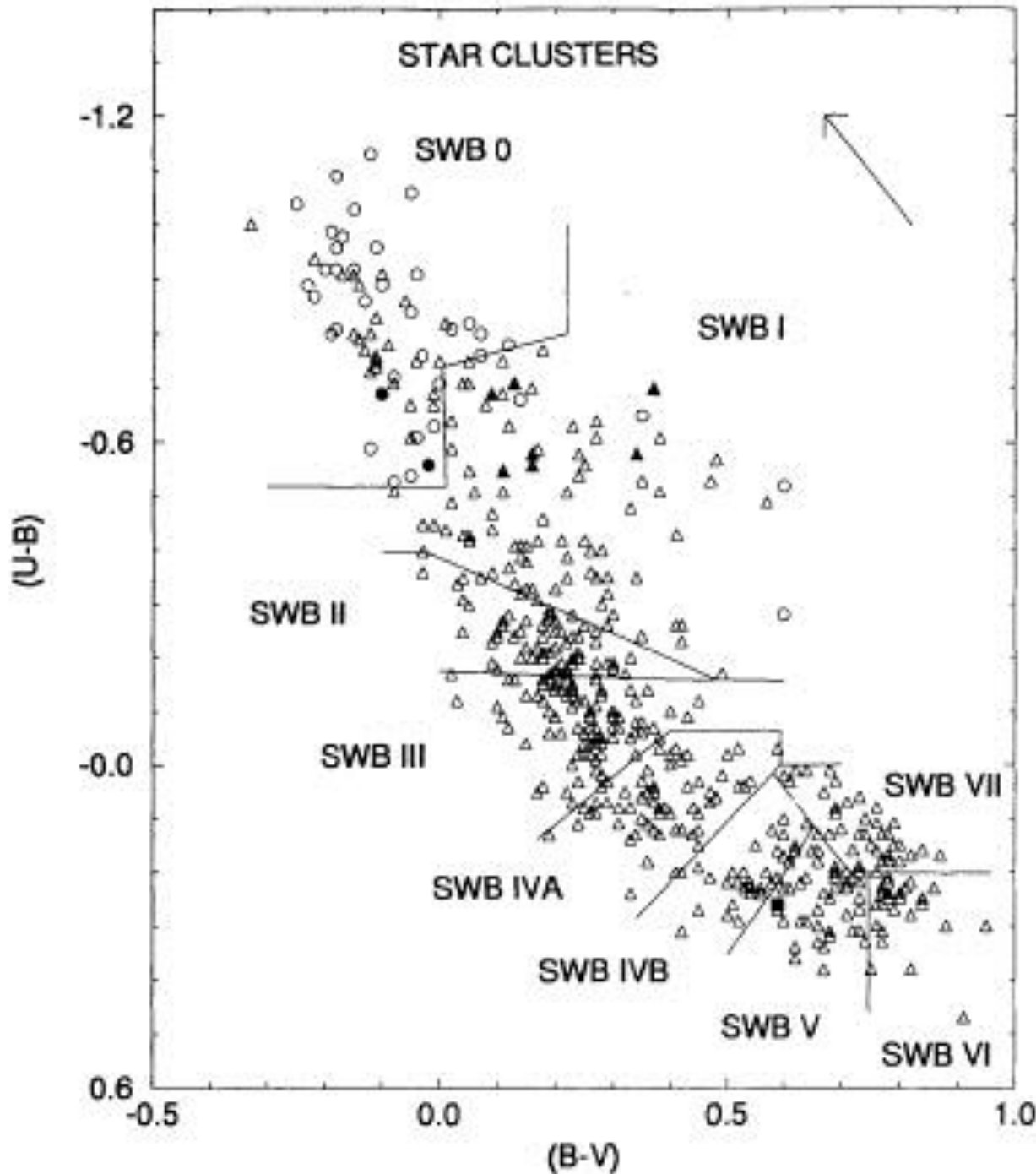
For LMC and SMC
(open circles)

Age: I, II and III

Age and Metallicity:
IV - VII

Integrated colors of 624 Star Clusters in the LMC

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



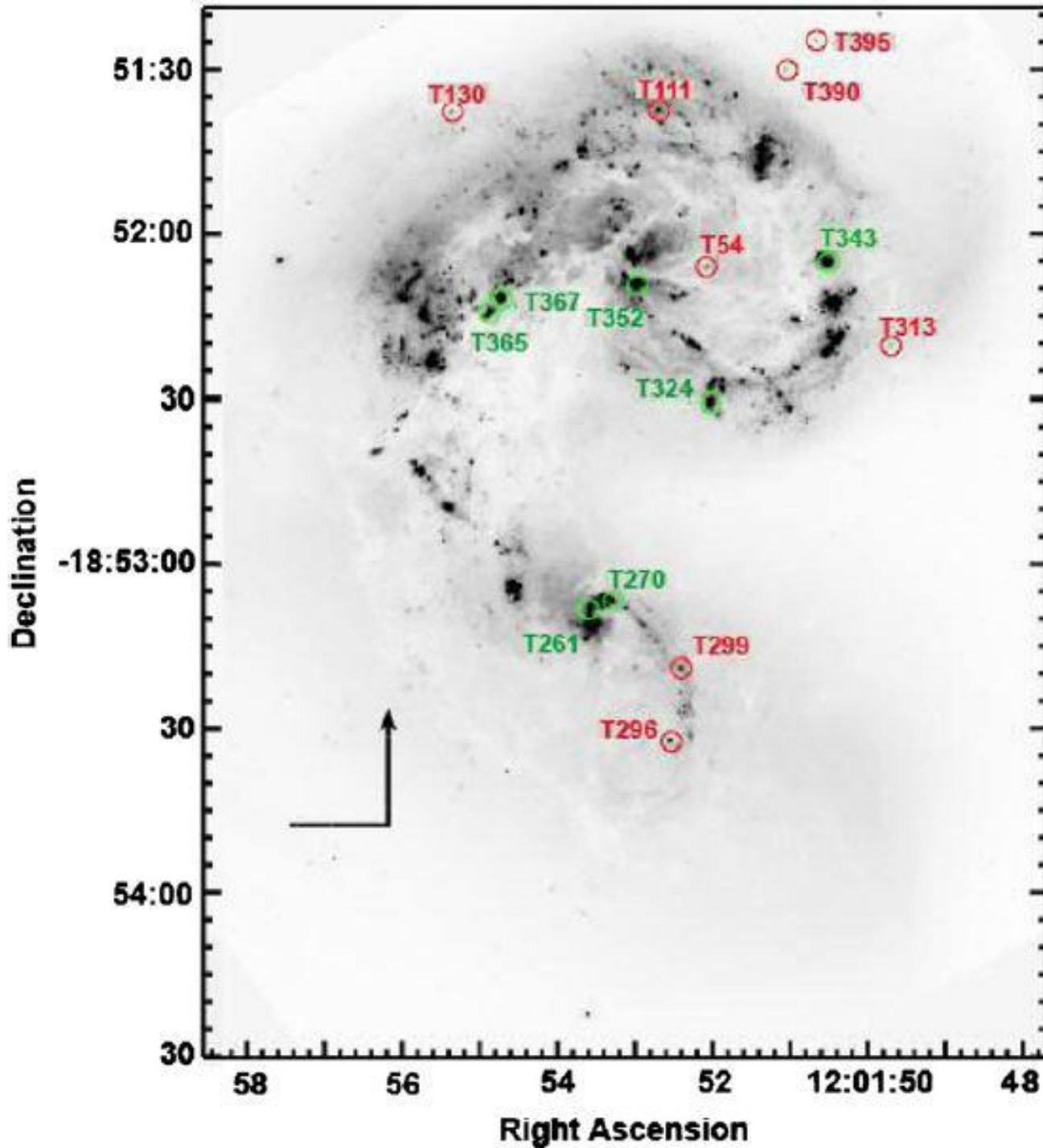
Group (SWB)	Age (Myr)	Clusters ^a	Associations ^a	Total	M	m	M/m	PA	x_c	y_c
0	0–10	61	77	138	6.3	6.3	1.00	140°	−0.11	1.14
I	10–30	89	41	130	6.7	6.3	1.00	150	−0.13	1.08
II	30–70	64	1	65	8.6	6.7	1.28	80	0.01	0.64
III	70–200	86	1	87	9.3	7.0	1.33	40	−0.40	0.48
IVA	200–400	62	0	62	11.6	8.0	1.45	10	−0.29	1.00
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
Total	0–16000	504	120	624	(25.5 ^b) 25.5 ^b	(15.6 ^b) 15.6 ^b	(1.63 ^b) 15.6 ^b	(0 ^b) 0 ^b	(−0.64 ^b) −0.28	(1.16 ^b) 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

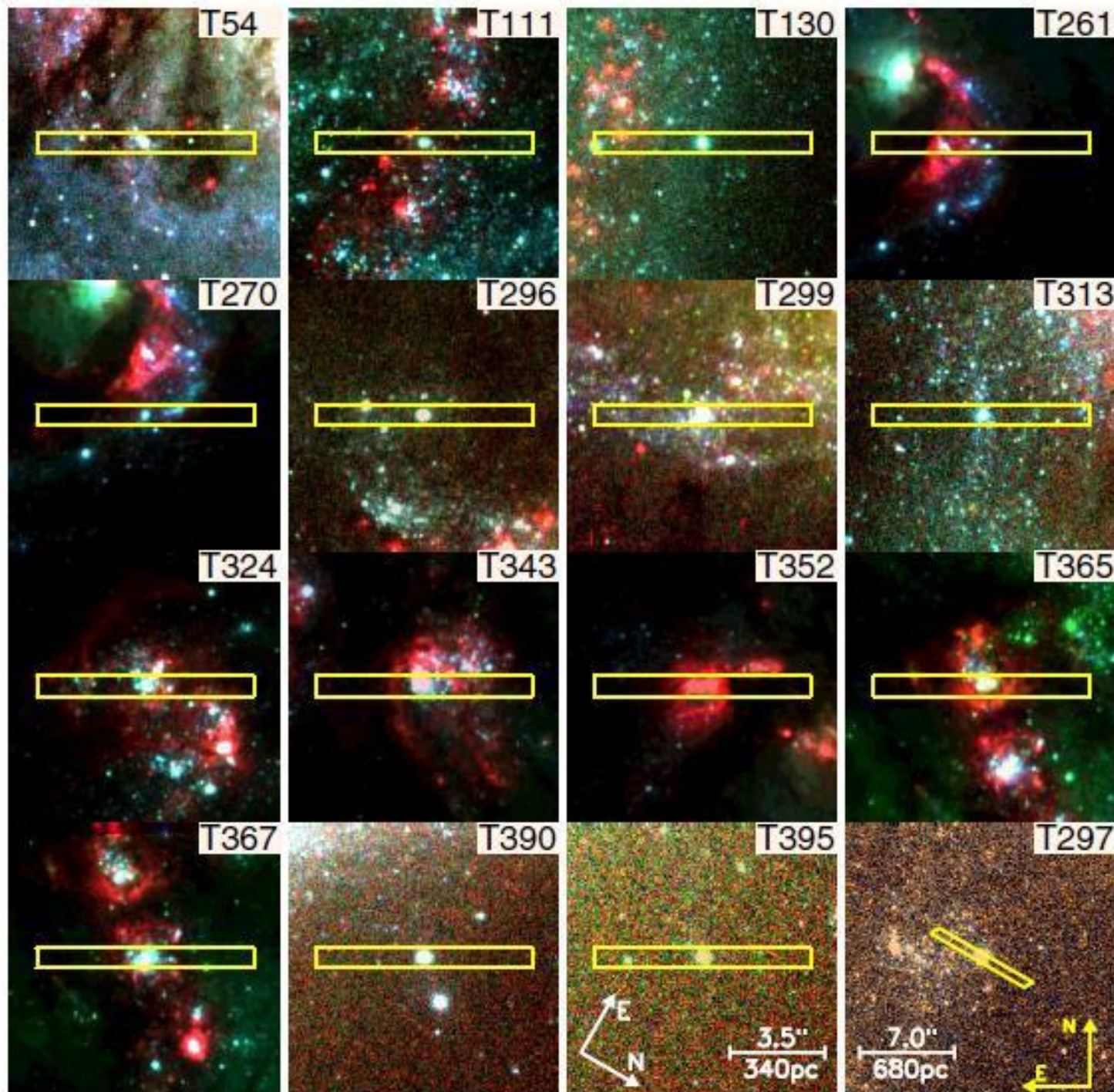


Star Clusters
in NGC 4038/9

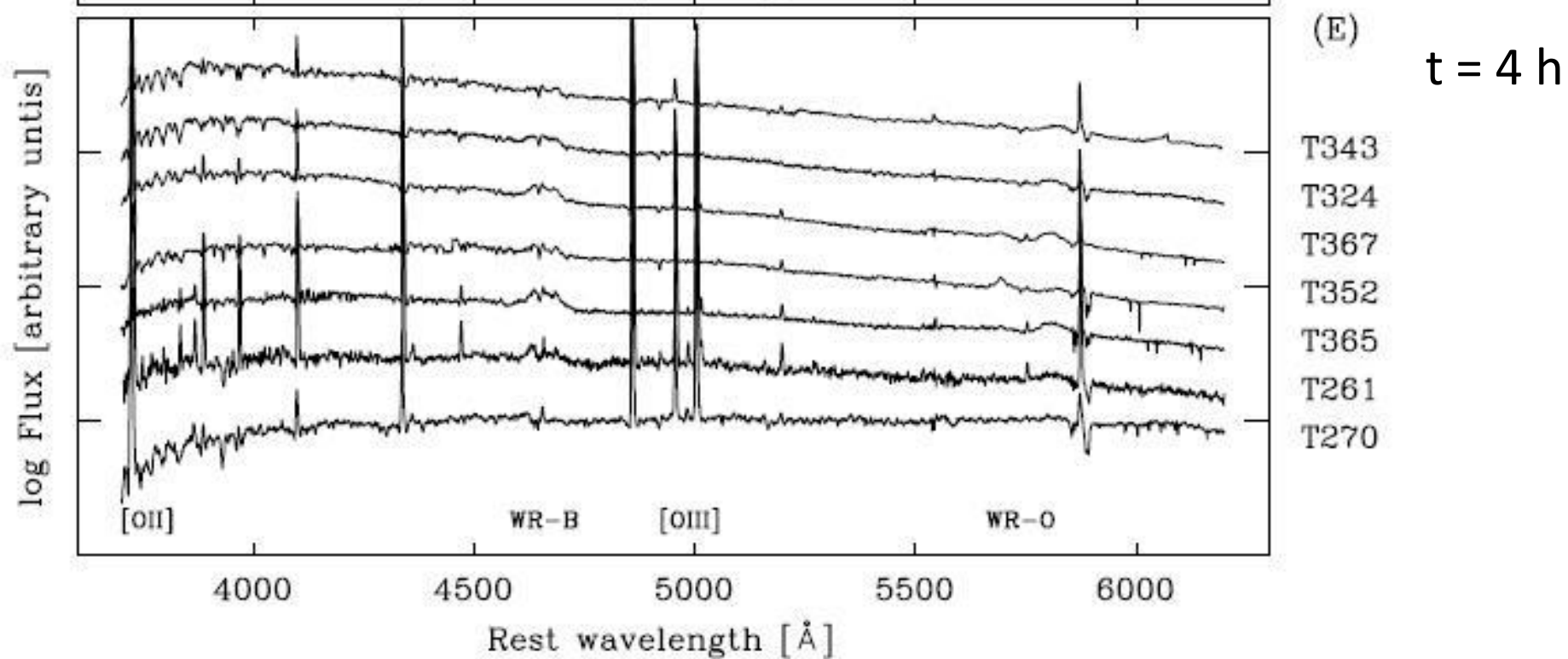
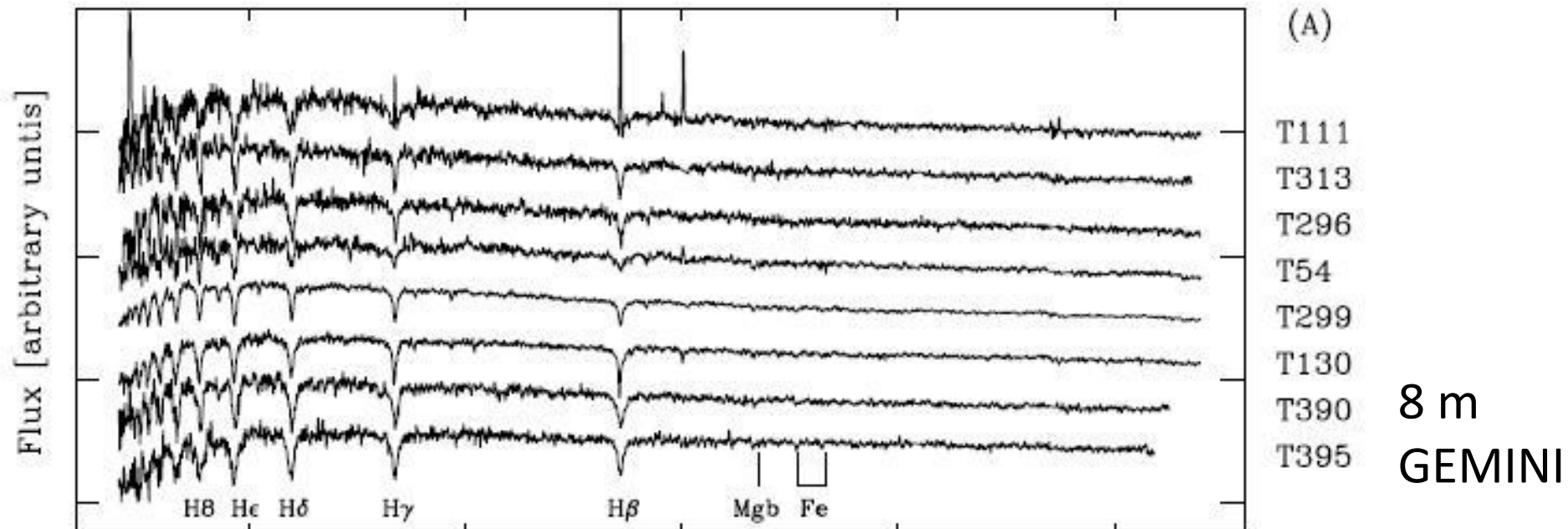
Antennae Galaxy

D = 20 Mpc

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



Positions
of the
slit



ID	H + H ϵ^a (Å)	K ^a (Å)	H8 ^a (Å)	H γ_{Λ}^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	Δ R.A. (J2000)	Δ Decl. (J2000)	F336W (mag)	F435W (mag)	F550M (mag)	F814W (mag)	F658N (mag)	A_V (mag)	Z (Z_\odot)	Log(age) (year)
T54	0	12 ^h 01 ^m 52 ^s .119	-18 ^d 52 ^m 07 ^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 ^h 01 ^m 53 ^s .379	-18 ^d 51 ^m 39 ^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 ^h 01 ^m 55 ^s .360	-18 ^d 51 ^m 38 ^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 ^h 01 ^m 53 ^s .561	-18 ^d 53 ^m 07 ^s .9	18.90	20.17	20.29	20.14	18.76	0.3	1.1 ± 0.2	<6.8
T270	1	12 ^h 01 ^m 53 ^s .345	-18 ^d 53 ^m 07 ^s .6	19.61	20.14	19.70	18.91	19.38	1.7	1.1 ± 0.2	<6.8
T296	0	12 ^h 01 ^m 52 ^s .624	-18 ^d 53 ^m 33 ^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 ^h 02 ^m 00 ^s .112	-18 ^d 54 ^m 33 ^s .3	...	...	22.22 ^b	21.60 ^b	...	1.0	1.1 ± 0.1 ^c	8.5 ± 0.2 ^c
T299	0	12 ^h 01 ^m 52 ^s .480	-18 ^d 53 ^m 20 ^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 ^h 01 ^m 49 ^s .744	-18 ^d 52 ^m 21 ^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 ^h 01 ^m 52 ^s .085	-18 ^d 52 ^m 31 ^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 ^h 01 ^m 50 ^s .537	-18 ^d 52 ^m 06 ^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 ^h 01 ^m 53 ^s .022	-18 ^d 52 ^m 10 ^s .6	16.33	17.69	17.54	17.57	17.01	0.3	1.3 ± 0.2	<6.8
T365	2	12 ^h 01 ^m 54 ^s .928	-18 ^d 52 ^m 15 ^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 ^h 01 ^m 54 ^s .749	-18 ^d 52 ^m 12 ^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 ^h 01 ^m 51 ^s .076	-18 ^d 51 ^m 31 ^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 ^h 01 ^m 50 ^s .681	-18 ^d 51 ^m 26 ^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(H I) ^b (km s ⁻¹)	czhel (km s ⁻¹)	deltcz (km s ⁻¹)	log(Mass) 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