

AGB stars in the Local Group, and beyond

Martin Groenewegen
groen@ster.kuleuven.ac.be

Instituut voor Sterrenkunde - K.U.Leuven

Overview

- Late-type stars
- How to find them?

Infrared colours

Variability

Narrow-band filters

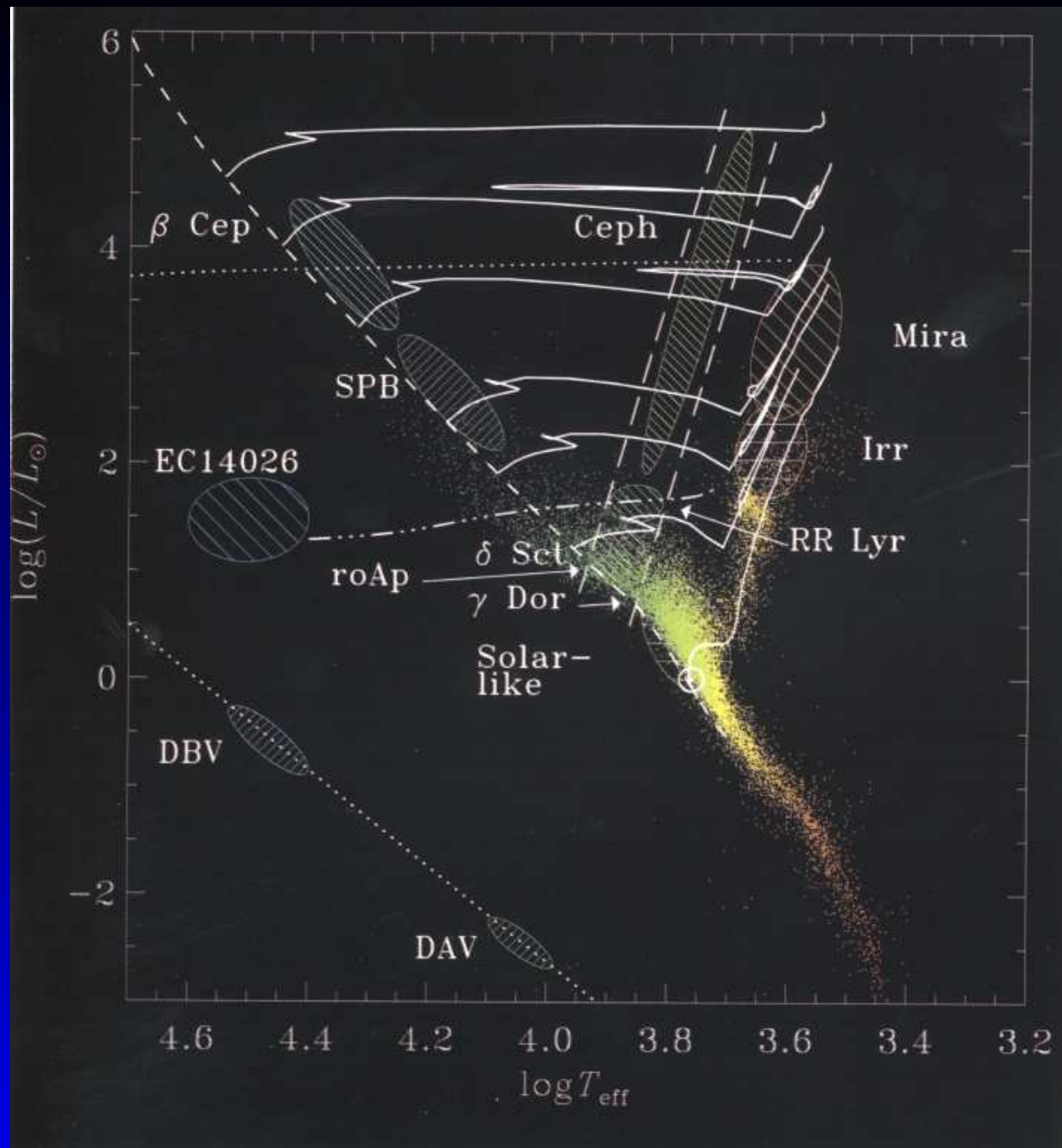
- Inventory / Status report

Update of:

Groenewegen (1999, IAU Symp 191)

Azzopardi (1999, Ap&SS 265, 291)

Groenewegen (Ringberg, astro-ph/0208449)



Evolutionary phases

Late-type stars

- Alternate H and He shell-burning
- All stars $\lesssim 7-8 M_{\odot}$ go through the AGB phase
- Exact $M \rightarrow S \rightarrow C$ sequence is uncertain

depends on:

-initial mass

- Z

-mass loss

-dredge-up

-Hot Bottom Burning

C-star formation: $M_{\text{initial}} \gtrsim 1.5 M_{\odot}$ (solar),

$M_{\text{initial}} \gtrsim 1.3 M_{\odot}$ (LMC)

Late-type stars

- Carbon stars ($C/O \geq 1$)

N-type

“infrared carbon stars”

R-type

CH-type

carbon dwarfs (pollution by present-day WD)

- S-stars ($0.95 \lesssim C/O < 1$)

“intrinsic”

“extrinsic” (pollution by present-day WD)

Late-type stars

- Oxygen-rich stars ($C/O \lesssim 0.95$)

Giants of spectral type M, MS

OH/IR stars

Barium stars (pollution by present-day WD)

In general:

Stars which show Tc are presently on the AGB

How to identify late-type stars ?

- **Infra-red broadband photometry**

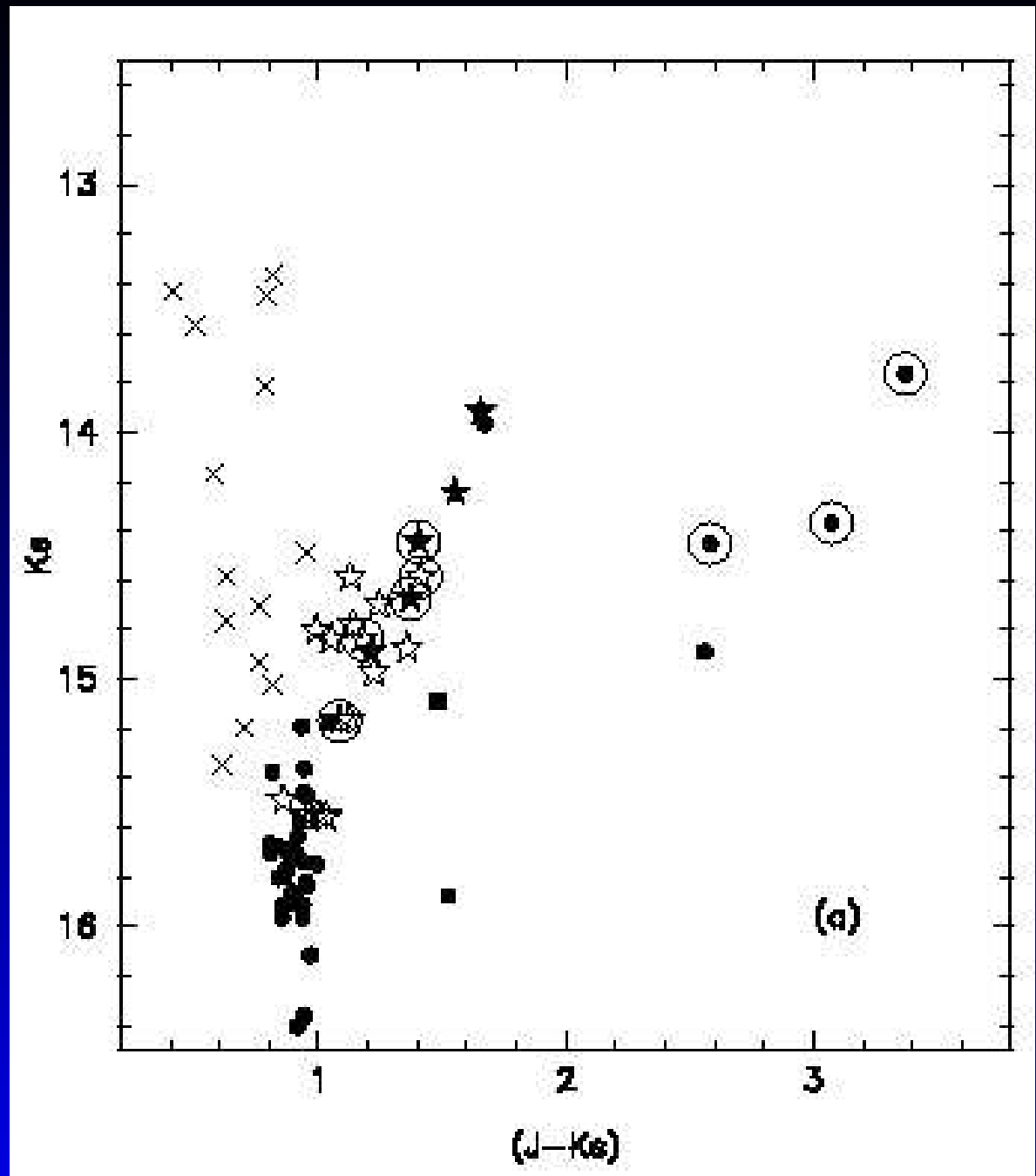
Disadvantage:

Candidates only,

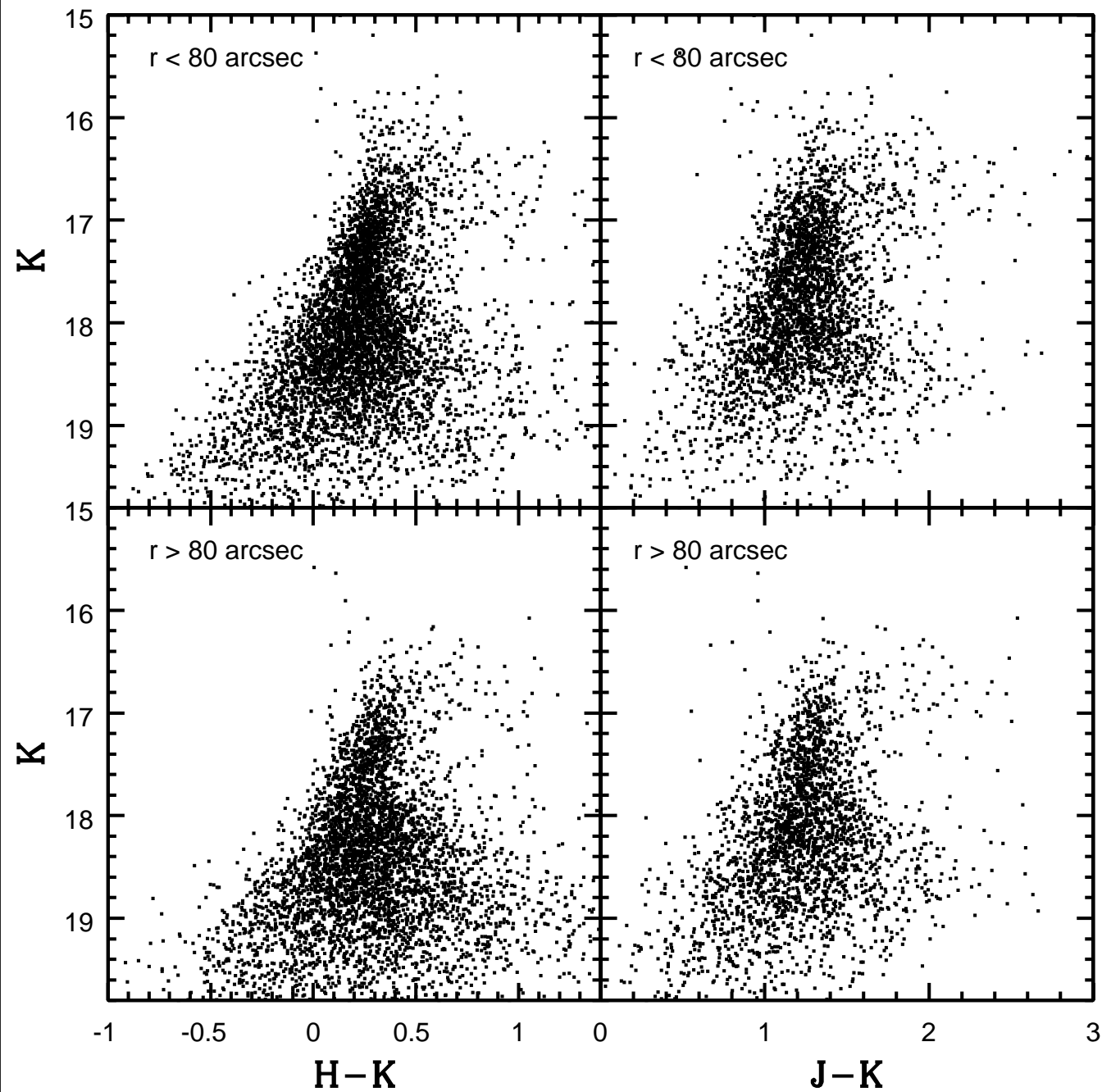
$(J - K)$ colour is often used as discriminant M/C

Advantage:

Very red colours traces different population



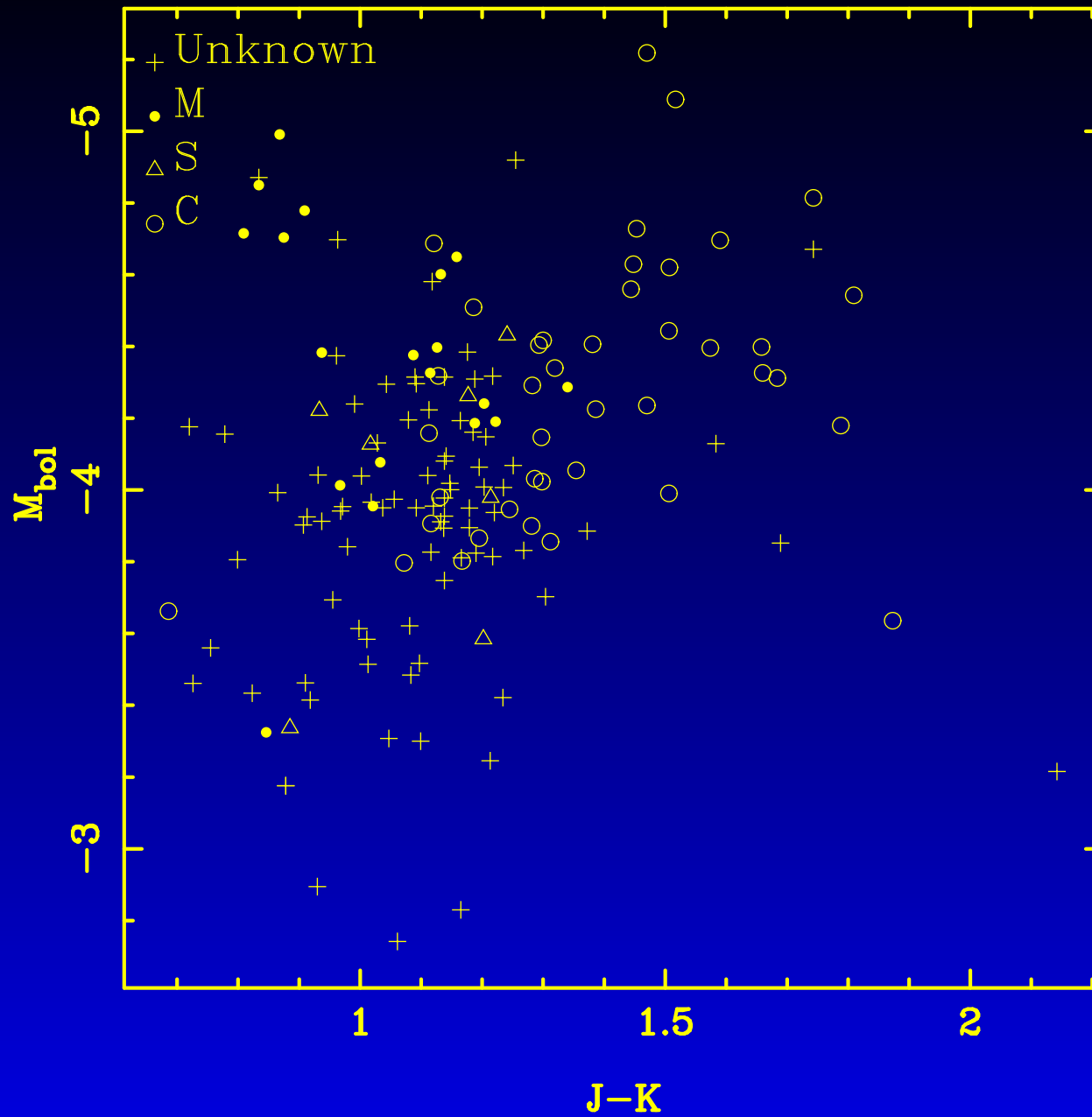
Menzies et al. (2002) for Leo I



Davidge (2003) for NGC 205

2MASS/DENIS

- Demers et al. (2002): C-stars in MCs and Fornax
- Cioni et al. (2003): spatial C/M ratio over MCs
- G02: correlated known C-stars in DSph
- G02: correlation with 164 known red stars from Stetson et al. (1998); 155 matches



Fornax (Groenewegen 2002)

2MASS/DENIS

- Demers et al. (2002): C-stars in MCs and Fornax
- Cioni et al. (2003): spatial C/M ratio over MCs
- G02: correlated known C-stars in DSph
- G02: correlation with 164 known red stars from Stetson et al. (1998); 155 matches
- Marescaux (2003): all LG galaxies within 1 Mpc (excluding MCs, M31, M32)
($J - K)_0 > 1.22$, appropriate M_K -range,
SIMBAD

2MASS:

candidate infrared AGB stars

Name	D (kpc)	$N_{2\text{mass}}$	N_C
Ursa Minor	69	8	7
Sculptor	79	8	8
Draco	82	6	6
Sextans	86	10	(0)
Carina	100	6	11
Fornax	138	34	104
Leo II	205	1	8
Leo I	250	2	23
NGC 6822	490	6	904
LGS 3	620	1	?
IC 10	660	9	?
IC 1613	720	3	195
NGC 147	755	1	288
And I	790	1	0
Leo A	800	2	?
Tucana	870	1	0

How to identify late-type stars ?

- **Variability**

Disadvantage:

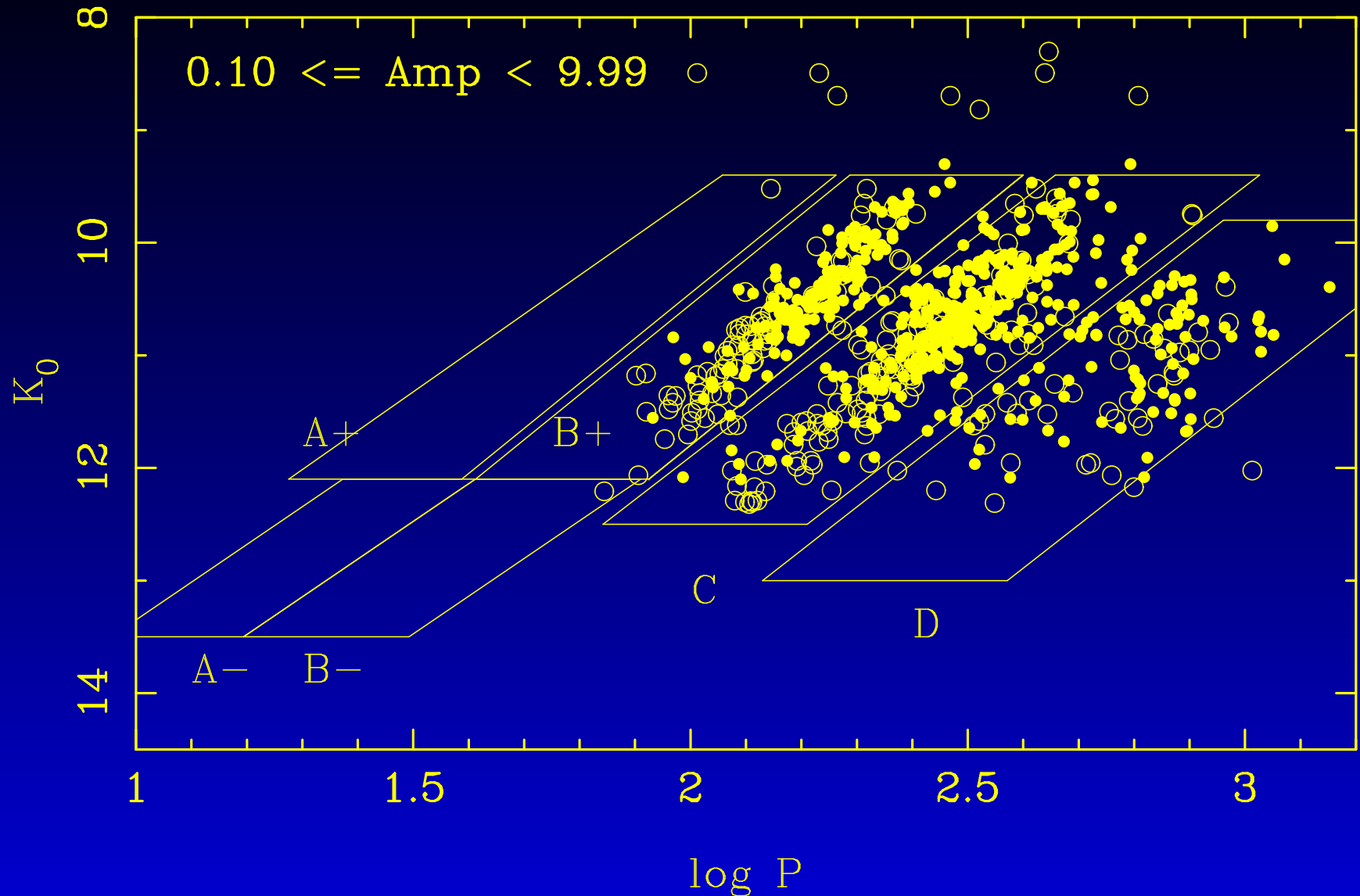
No M/S/C discrimination

Observing time demanding

Advantage:

PL-relation

Distance estimates



Pioneered by Wood (1999, 2000).

G04: LMC, spectroscopically selected sample.

Variability

- MCs
(Wood, Noda, Lebzelter, Cioni, Ita, Kiss, Glass)
- Bersier & Wood (2002):
85 LPV candidates in Fornax
- Snigula et al. (2003):
16 / 5 LPV candidates in Leo A / GR 8
- Gallart et al. (2004):
6 LPV candidates in Phoenix
- Rejkuba (2004):
240 well defined Miras in NGC 5128

How to identify late-type stars ?

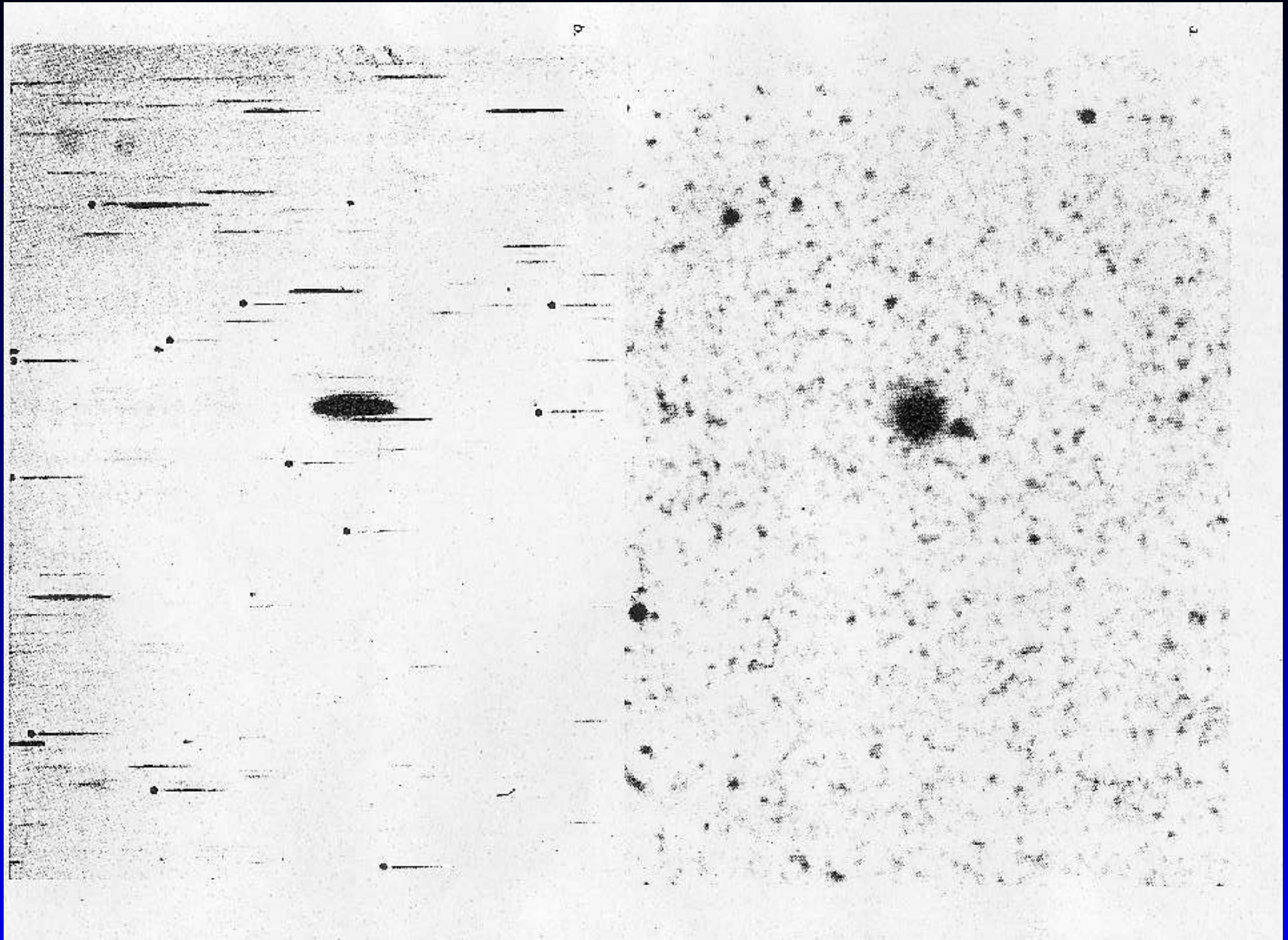
- GRENS, GRISMS

Azzopardi and Westerlund

CN bands near 8000 Å

C₂ bands 4737, 5165 Å

disadvantage: crowding, sensitivity



Westerlund 1978

How to identify late-type stars ?

- Narrow-band filters

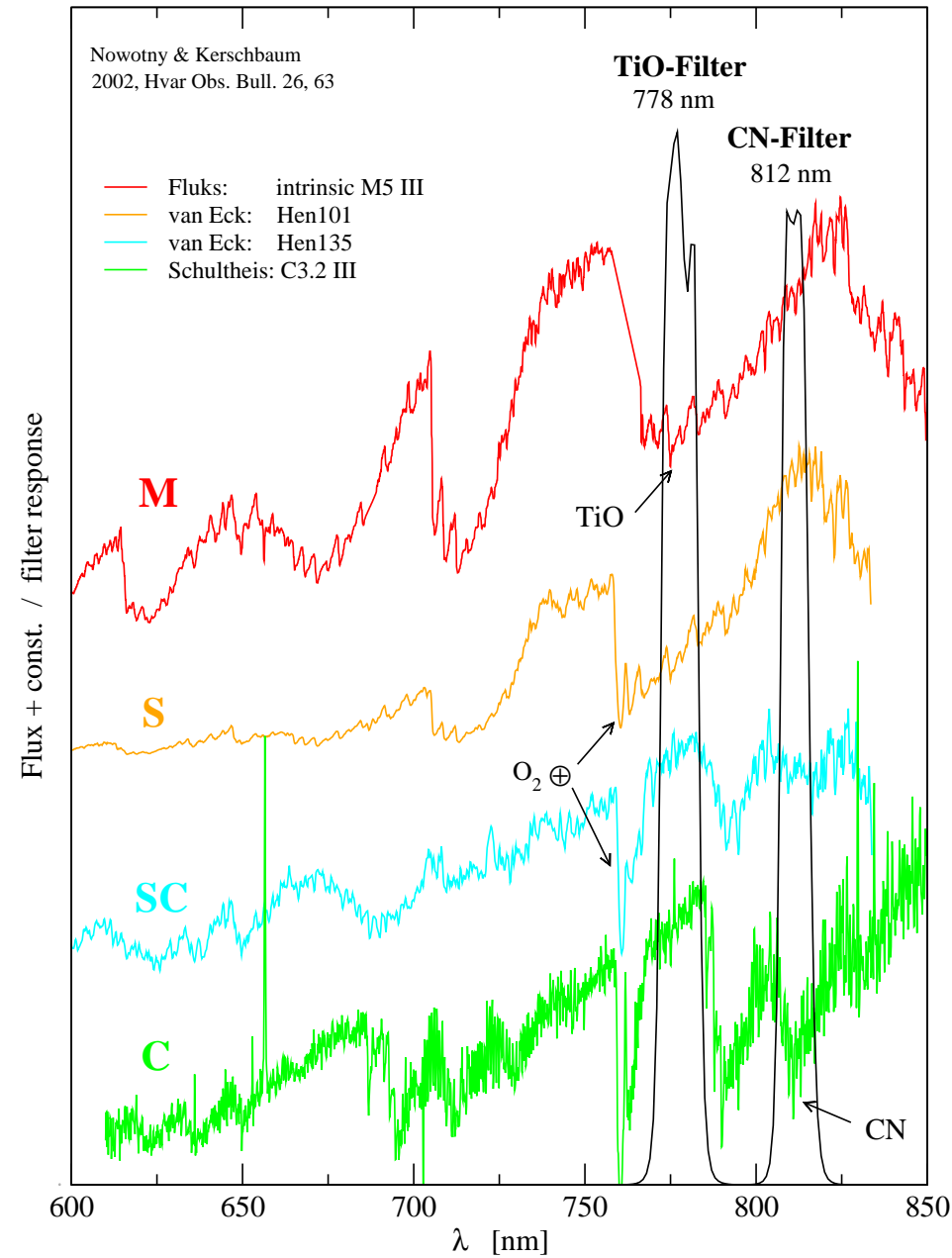
Richer et al. (1984); Aaronson et al. (1984)

broad-band V, R, I + narrow-band 7800, 8100

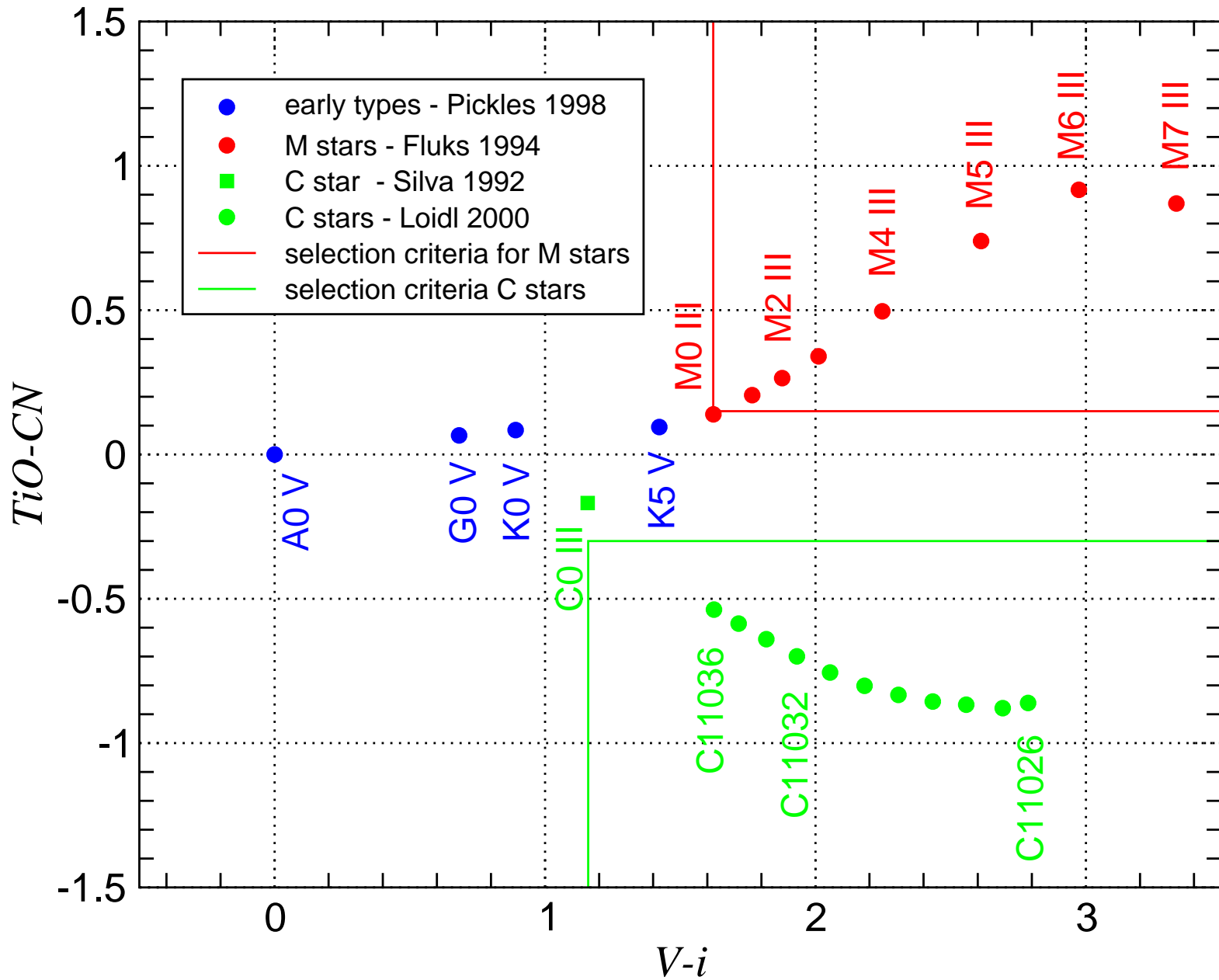
advantage: spectroscopic identification

disadvantage: foreground M-stars

Spectra of AGB stars with different chemistry
+ Wing-type narrow-band filters



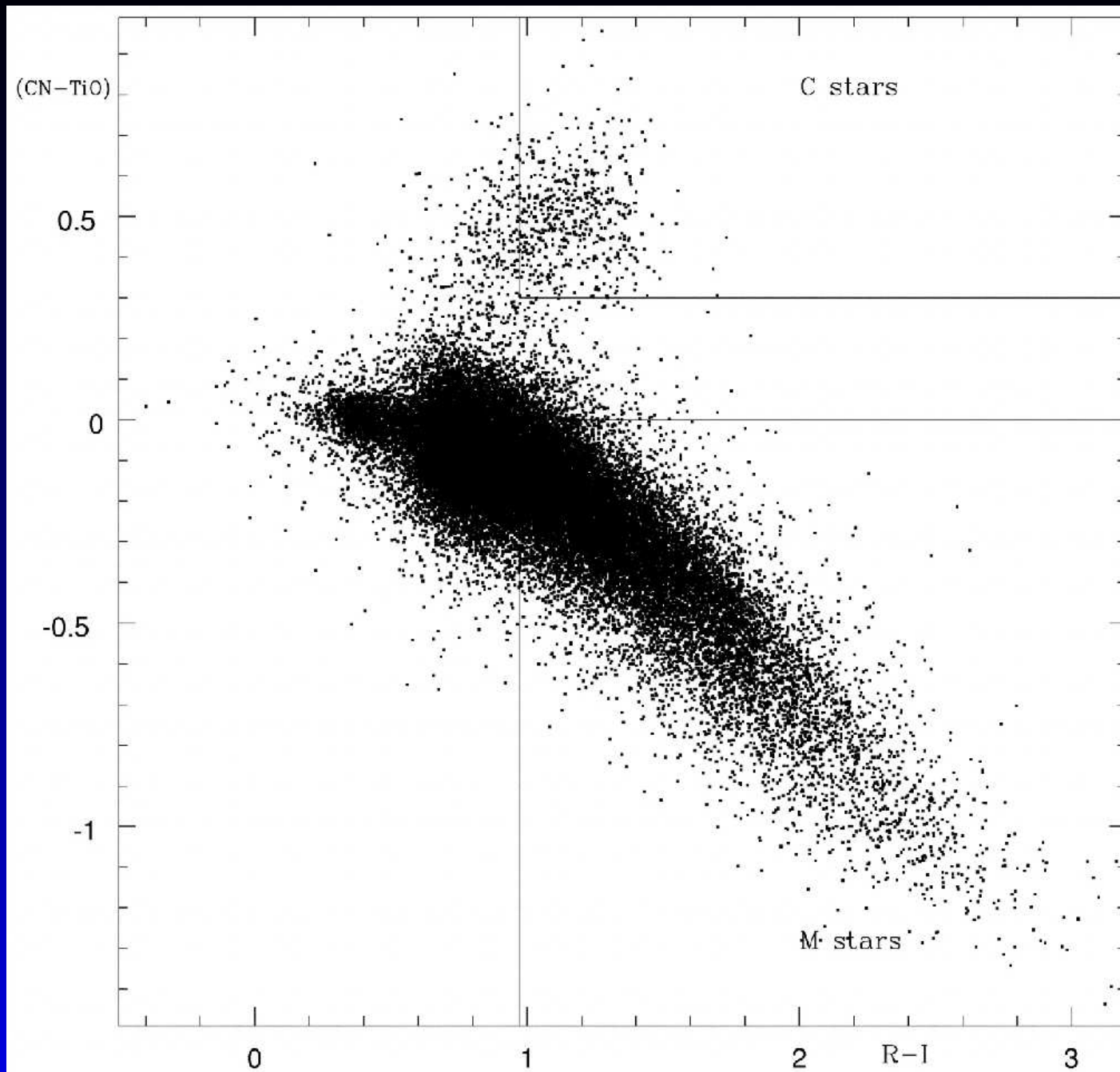
Synthetic Photometry



Nowotny & Kerschbaum 2002

Recent surveys (> 2002)

- Battinelli/Demers/LeTarte (2003-2004):
outer disk of M31, NGC 205, NGC 3109,
NGC 147, NGC 185, WLM
- Nowotny et al. (2003): NGC 147, NGC 185
- Harbeck (2004): And III, V, VI, VII, NGC 147,
Cetus DSph



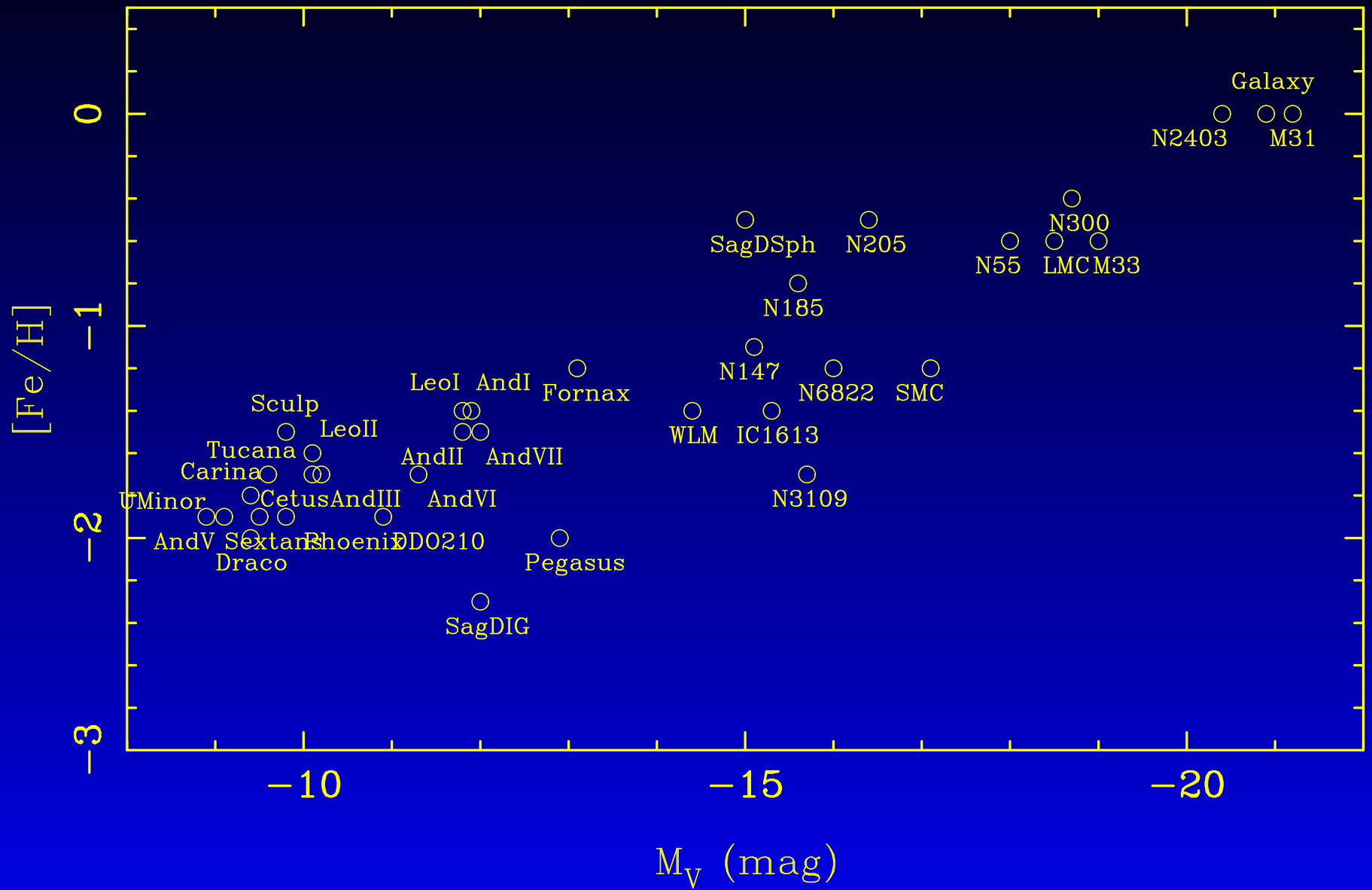
Demers et al. (2003) for NGC 205

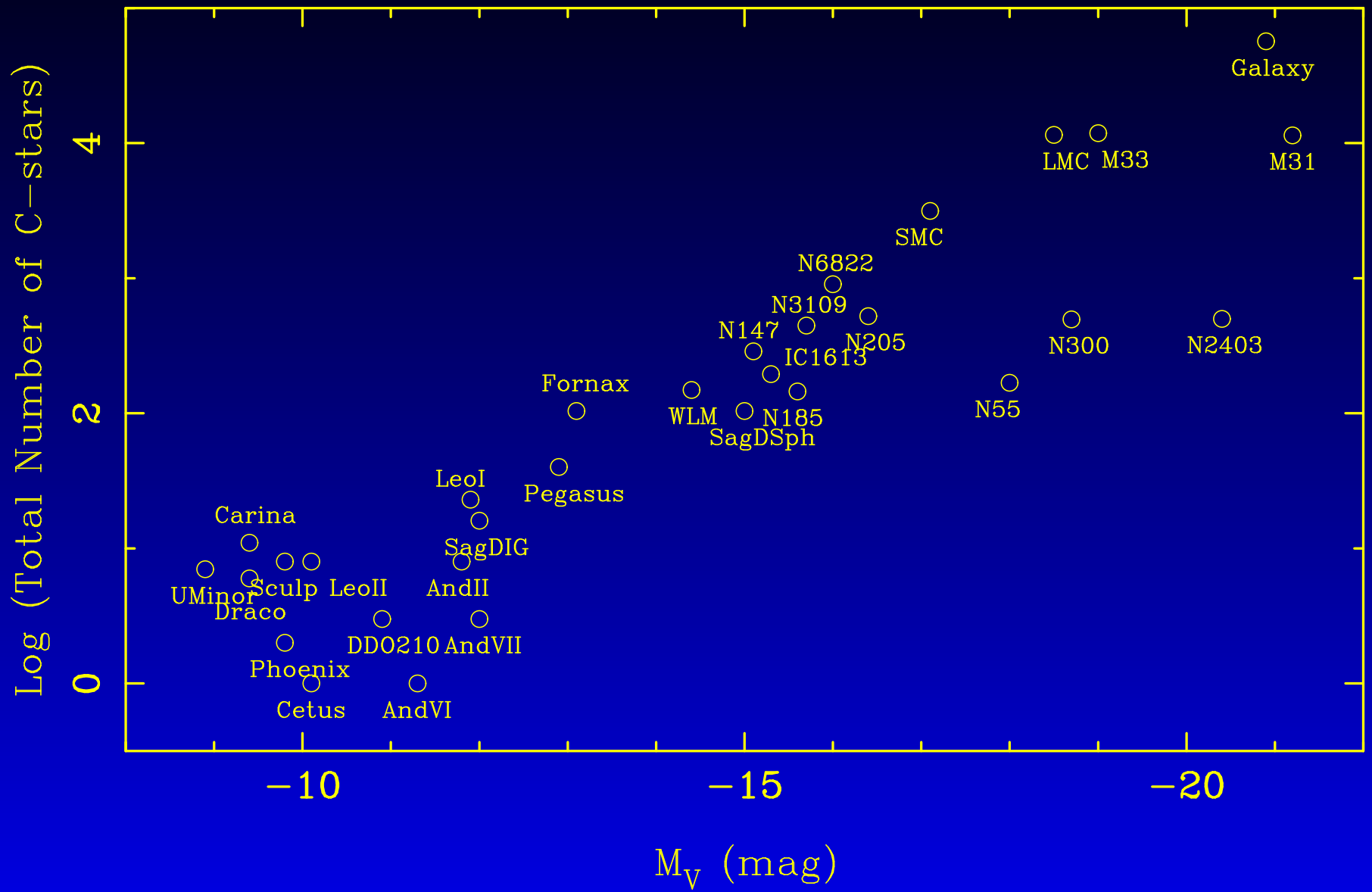
Name	D	M_V	[Fe/H]	N_C	Area	N_M
	(kpc)	(mag)			(kpc ²)	
M31	770	-21.2	0.0	243	12.3	789 (5+)
Galaxy		-20.9	0.0	81	1.00	C/M \approx 0.2
M33	840	-19.0	-0.6	15	0.20	5 (5+), 60 (0+)
LMC	50	-18.5	-0.6	1045	4.8	1300 (5+)
				7750	220.	
SMC	63	-17.1	-1.2	789	5.4	180 (5+)
				1707	12.2	
NGC 205	830	-16.4	-0.8	7	0.33	4 (5+), 17 (0+)
(new)				525	12.3	5830 (0+)
NGC 6822	490	-16.0	-1.2	904	4.5	941 (0+)
NGC 3109	1360	-15.7	-1.7	446	33	250 (0+)
NGC 185	620	-15.6	-0.8	145	4.5	850 (0+)

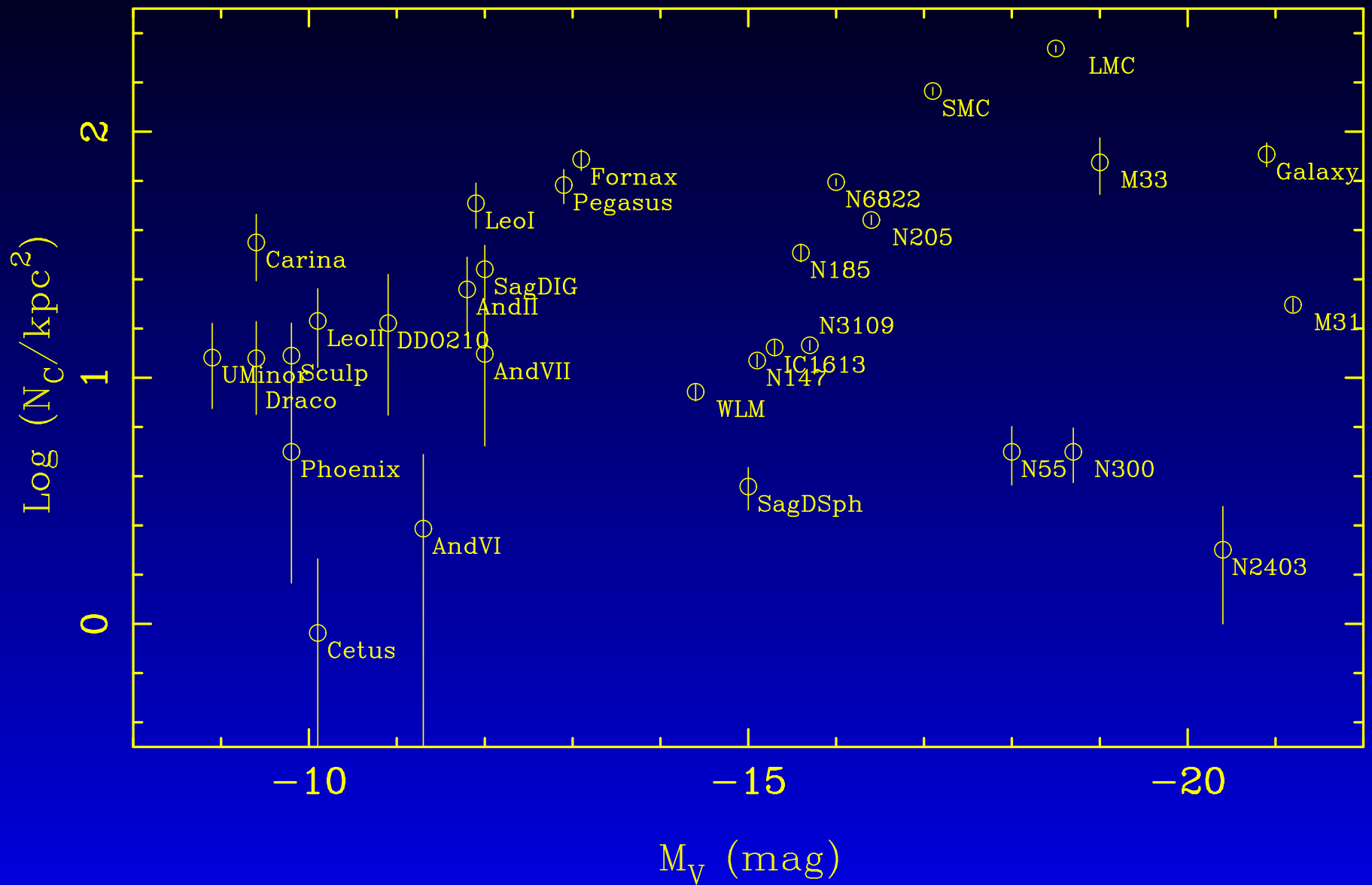
Name	D (kpc)	M_V (mag)	[Fe/H]	N_C	Area (kpc ²)	N_M
IC 1613	715	-15.3	-1.4	195	7.8	35 (5+), 300 (0+)
NGC 147	755	-15.1	-1.1	288	25.	1200 (0+)
SagDSph	28	-15.0	-0.5	26	7.2	
WLM	930	-14.4	-1.5	14	0.28	0 (5+), 6 (0+)
(new)				149	17.0	12 (0+)
Fornax	138	-13.1	-1.2	104	1.35	4 (5+), 25 (2+)
Pegasus	760	-12.9	-2.0	40	1.04	77 (0+)
SagDIG	1060	-12.0	-2.3	16	0.58	1 (0+)
Leo I	250	-11.9	-1.4	23	0.45	1 (5+), 15 (0+)
And I	790	-11.8	-1.4	0	0.33	
And II	680	-11.8	-1.5	8	0.35	1 (0+)
And III	760	-10.2	-1.7	0	0.66	

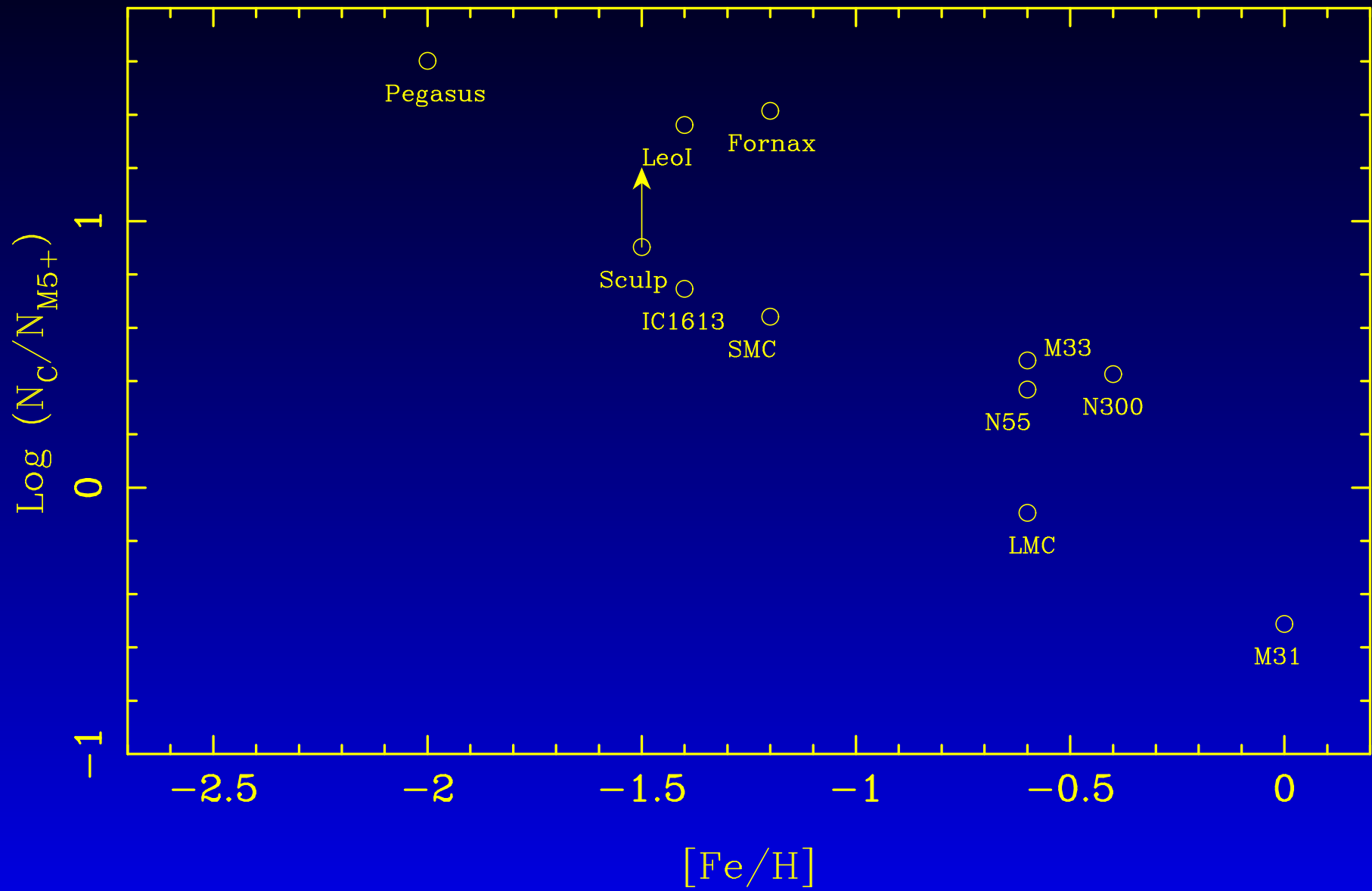
Name	D	M_V	[Fe/H]	N_C	Area	N_M
	(kpc)	(mag)			(kpc ²)	
And V	810	-9.1	-1.9	0	0.66	
And VI	775	-11.3	-1.7	1	0.41	
And VII	760	-12.0	-1.5	3	0.24	
DDO210	950	-10.9	-1.9	3	0.18	1 (0+)
Leo II	205	-10.1	-1.6	8	0.47	
Cetus	775	-10.1	-1.7	1	1.1	
Sculptor	88	-9.8	-1.5	8	0.65	40 (2+), 0 (5+)
Phoenix	405	-9.8	-1.9	2	0.40	
Tucana	870	-9.6	-1.7	0	0.22	
Sextans	86	-9.5	-1.9	(0)		
Draco	79	-9.4	-2.0	6	0.50	

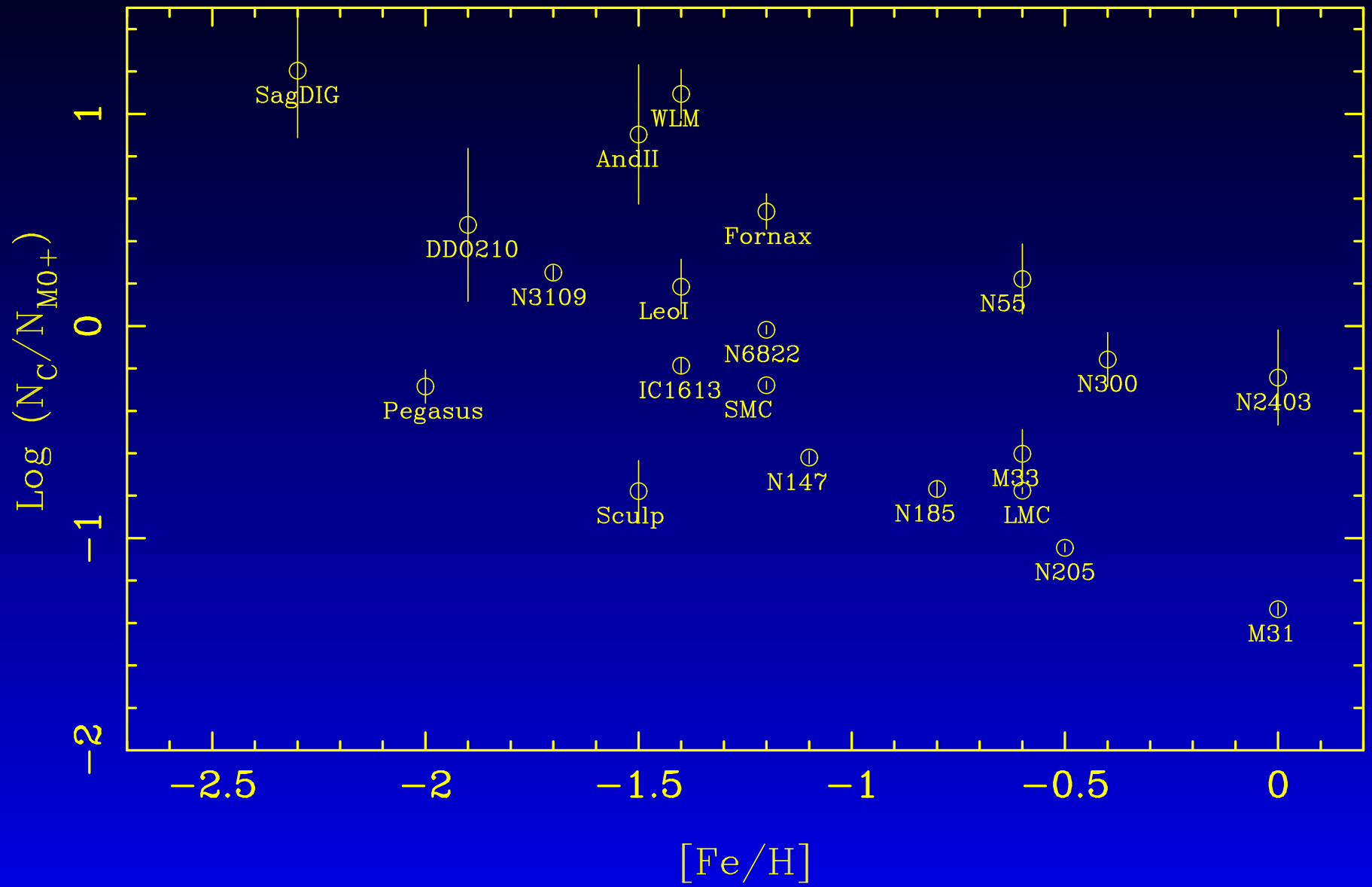
Name	D	M_V	[Fe/H]	N_C	Area	N_M
	(kpc)	(mag)			(kpc ²)	
Carina	94	-9.4	-1.8	11	0.31	
Ursa Minor	69	-8.9	-1.9	7	0.58	
NGC 2403	3390	-20.4	0.0	4	2.0	7 (0+)
NGC 300	2170	-18.7	-0.4	16	3.2	23 (0+), 6 (5+)
NGC 55	1480	-18.0	-0.6	14	2.8	6 (5+)

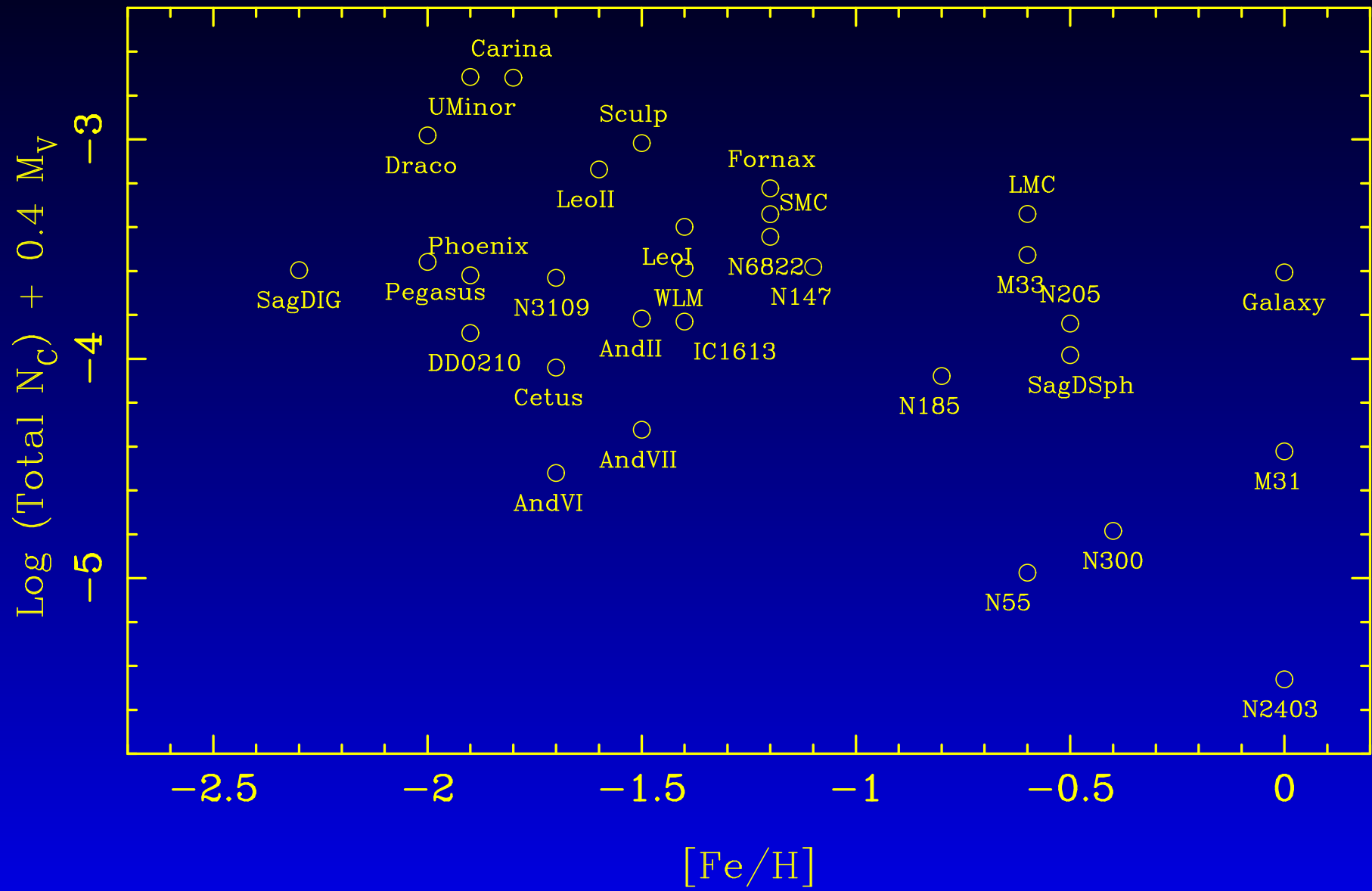








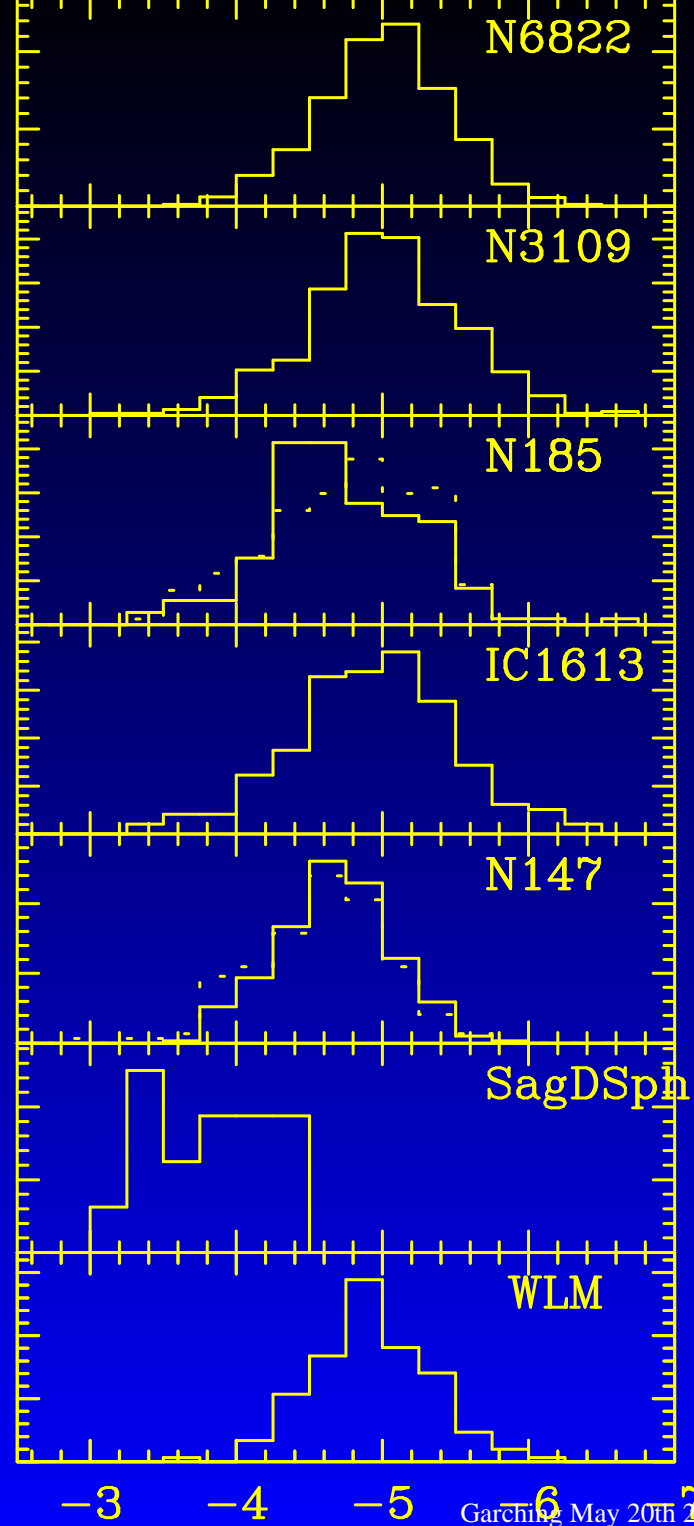
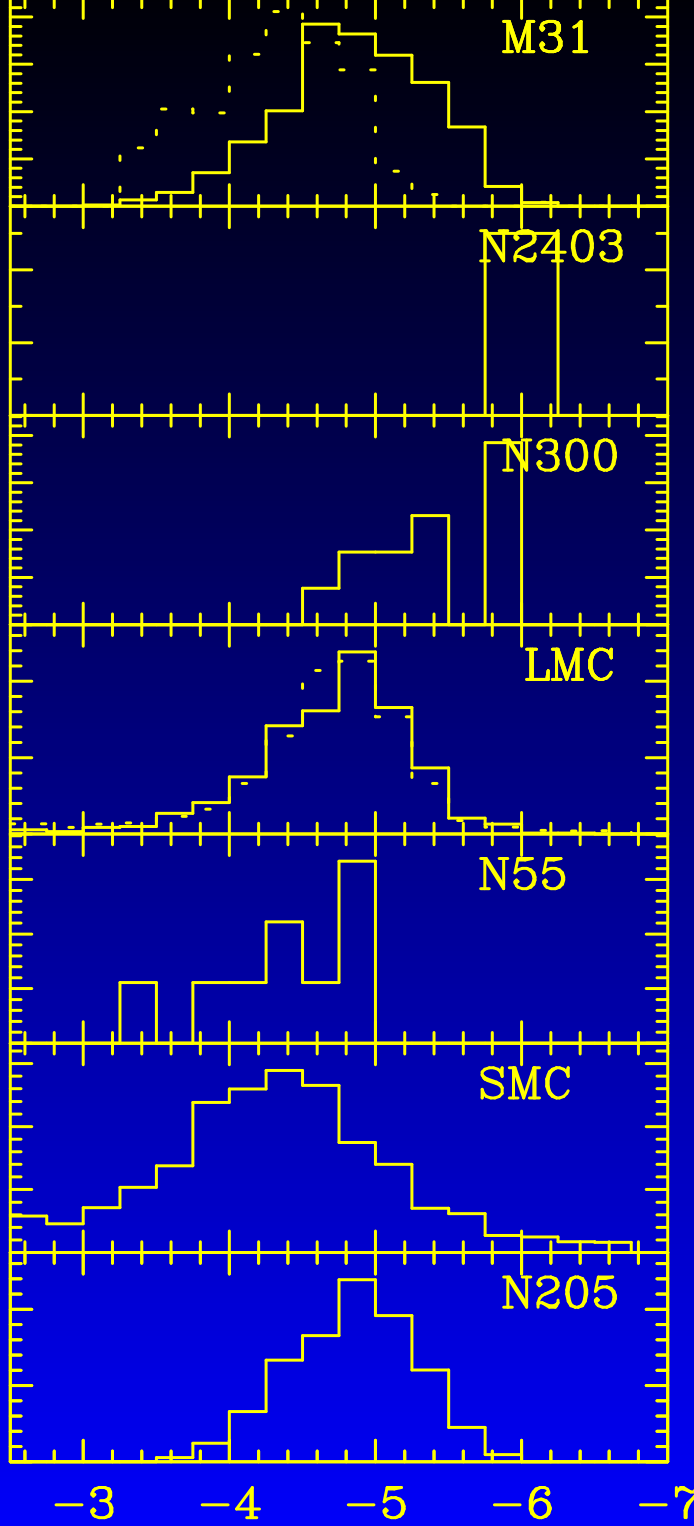


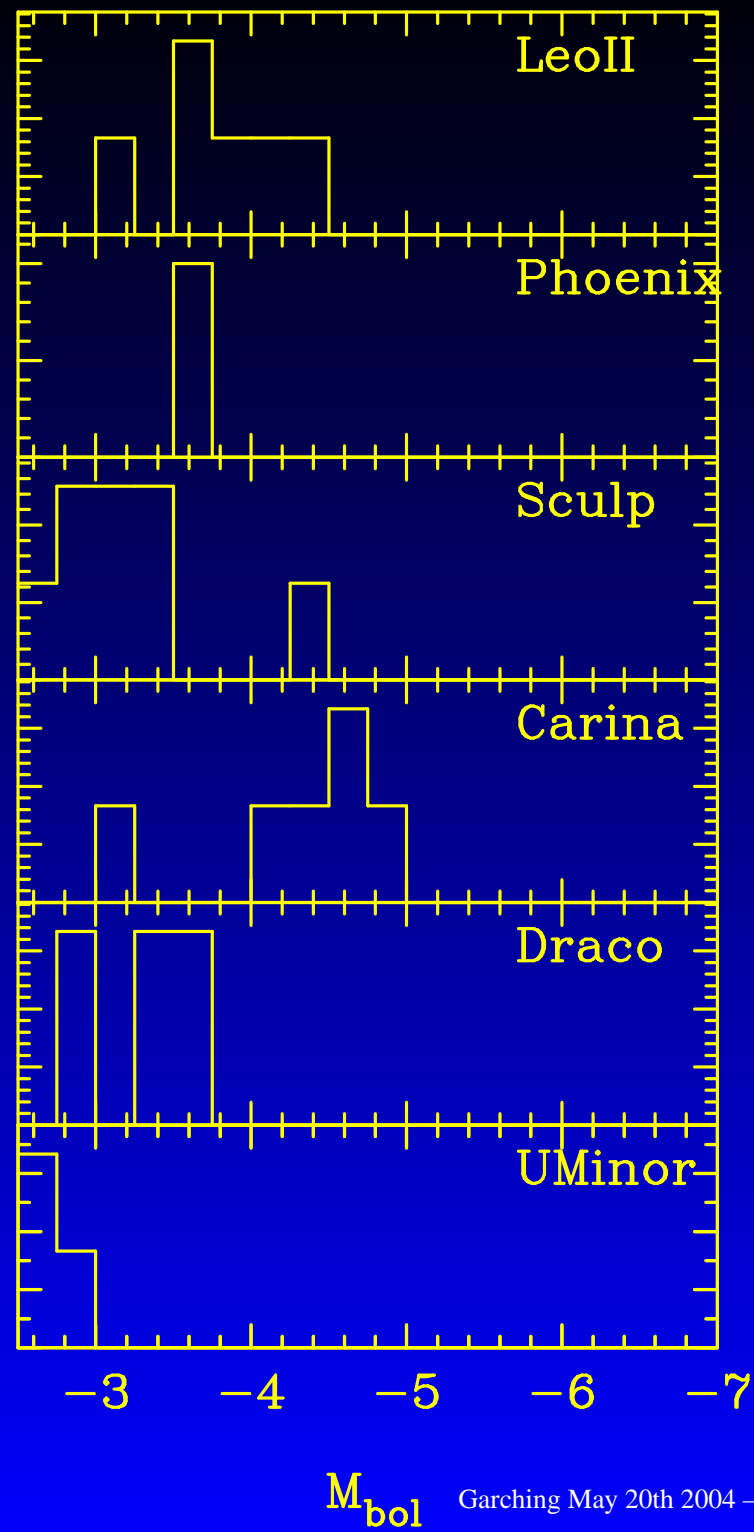
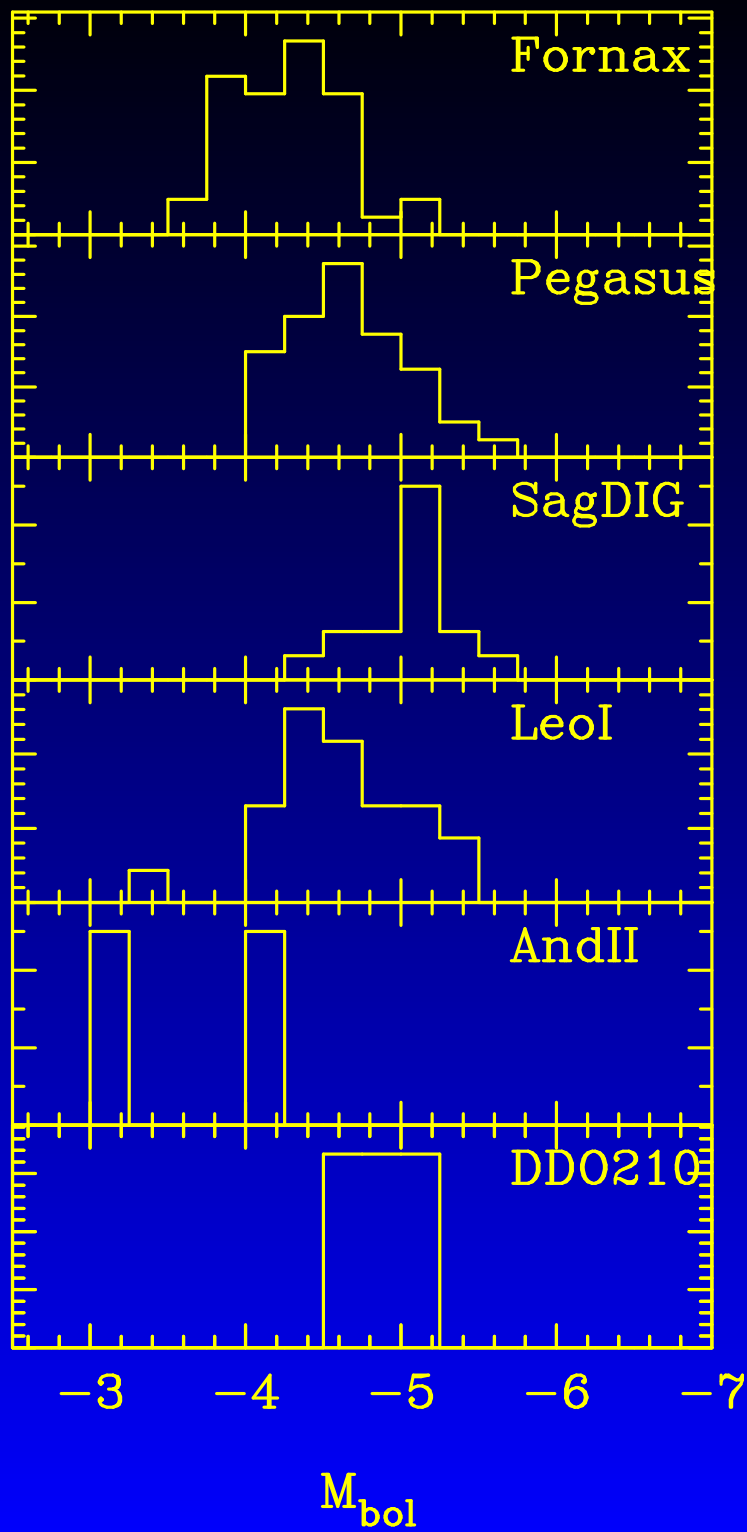


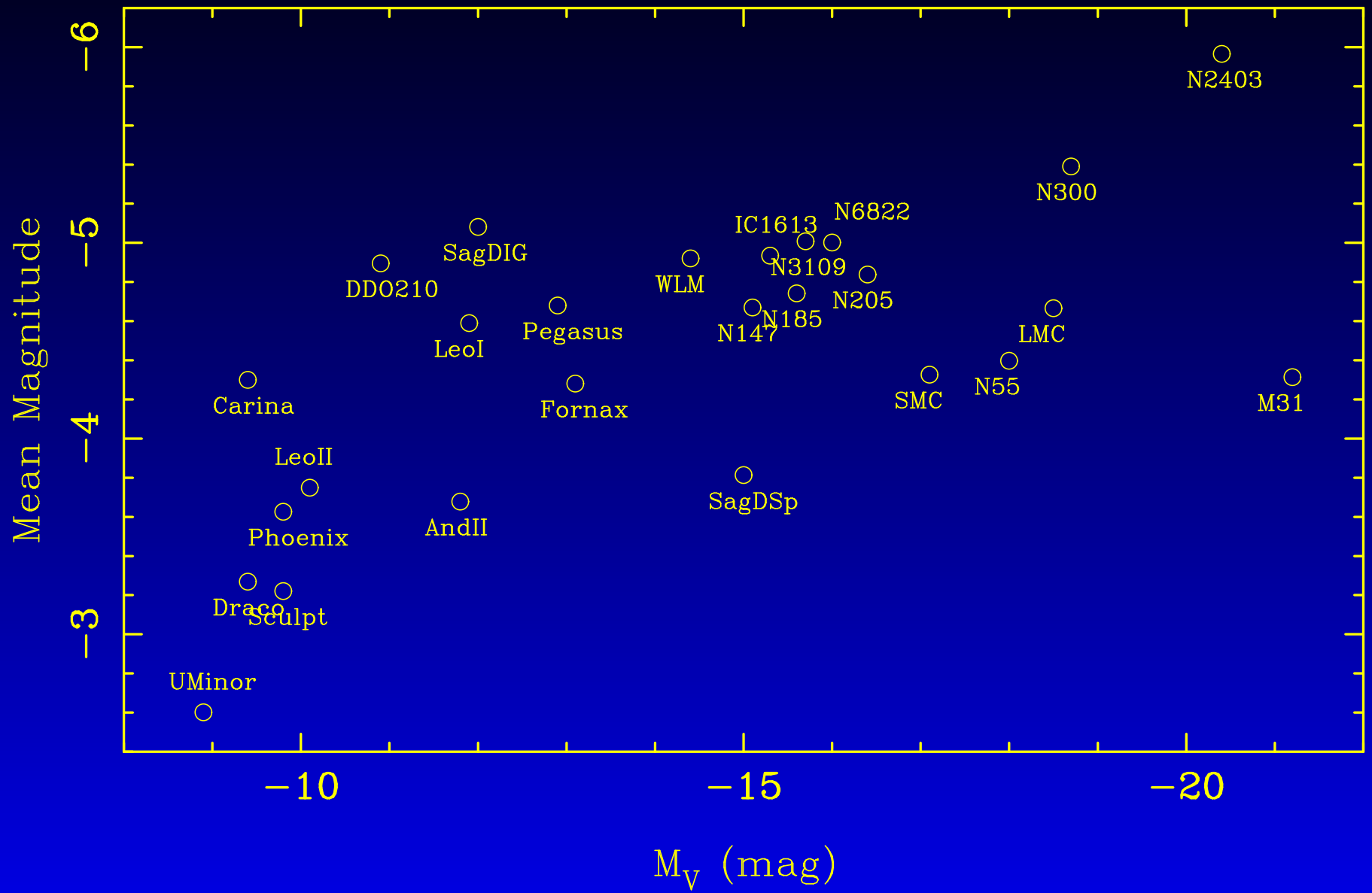
Name	$M_{\text{bol}}^{\text{max}}$	$M_{\text{bol}}^{\text{min}}$	$M_{\text{bol}}^{\text{mean}}$	spread	N_{all}	$N_{M_{\text{bol}} > -3.5}$
	(mag)	(mag)	(mag)	(mag)		
M31	-6.11	-3.35	-4.31	0.49	243	15
N2403	-6.05	-5.89	-5.97	0.08	4	0
N300	-5.93	-4.68	-5.39	0.41	13	0
LMC	-8.01	-1.33	-4.67	0.61	7650	378
N55	-4.98	-3.37	-4.40	0.51	9	1
SMC	-8.17	-1.62	-4.33	0.81	1626	226
N205	-5.88	-3.69	-4.84	0.43	532	0
N6822	-6.48	-3.65	-5.00	0.44	904	0
N3109	-7.16	-3.14	-5.01	0.53	446	2
N185	-7.68	-3.35	-4.74	0.56	145	2
IC1613	-6.34	-3.48	-4.94	0.56	195	2

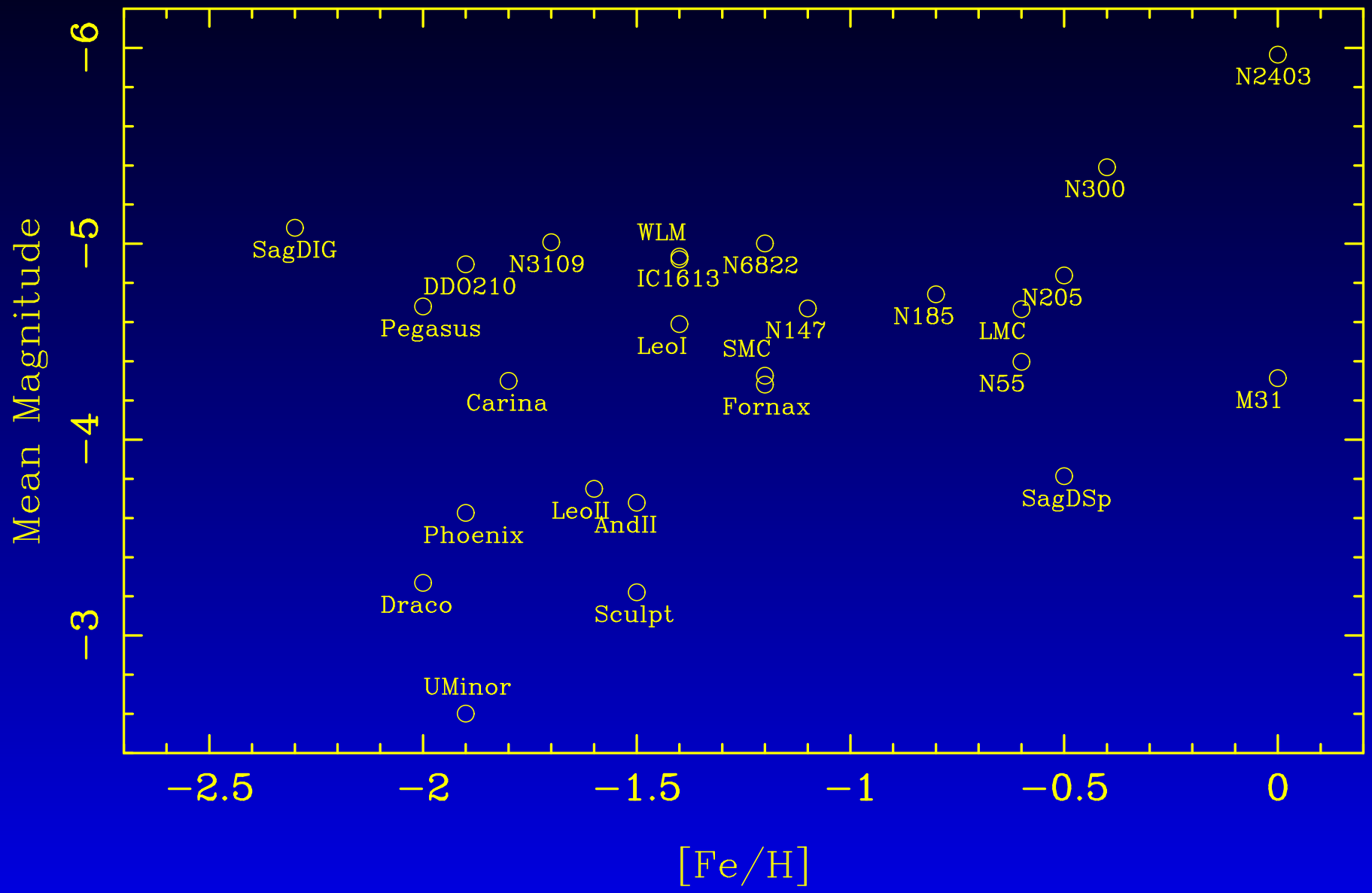
Name	$M_{\text{bol}}^{\text{max}}$	$M_{\text{bol}}^{\text{min}}$	$M_{\text{bol}}^{\text{mean}}$	spread	N_{all}	$N_{M_{\text{bol}} > -3.5}$
	(mag)	(mag)	(mag)	(mag)		
N147	-5.94	-3.53	-4.67	0.40	288	0
SagDSph	-4.37	-3.11	-3.81	0.40	16	5
WLM	-6.11	-3.73	-4.92	0.40	149	0
Fornax	-5.22	-3.64	-4.28	0.36	41	0
Pegasus	-5.59	-4.05	-4.68	0.37	40	0
SagDIG	-5.66	-4.48	-5.08	0.31	16	0
LeoI	-5.38	-3.32	-4.59	0.47	23	1
AndII	-4.11	-3.24	-3.68	0.62	2	1
DDO210	-5.12	-4.71	-4.89	0.21	3	0
LeoII	-4.26	-3.20	-3.75	0.37	6	1
Phoenix	-3.71	-3.55	-3.63	0.11	2	0

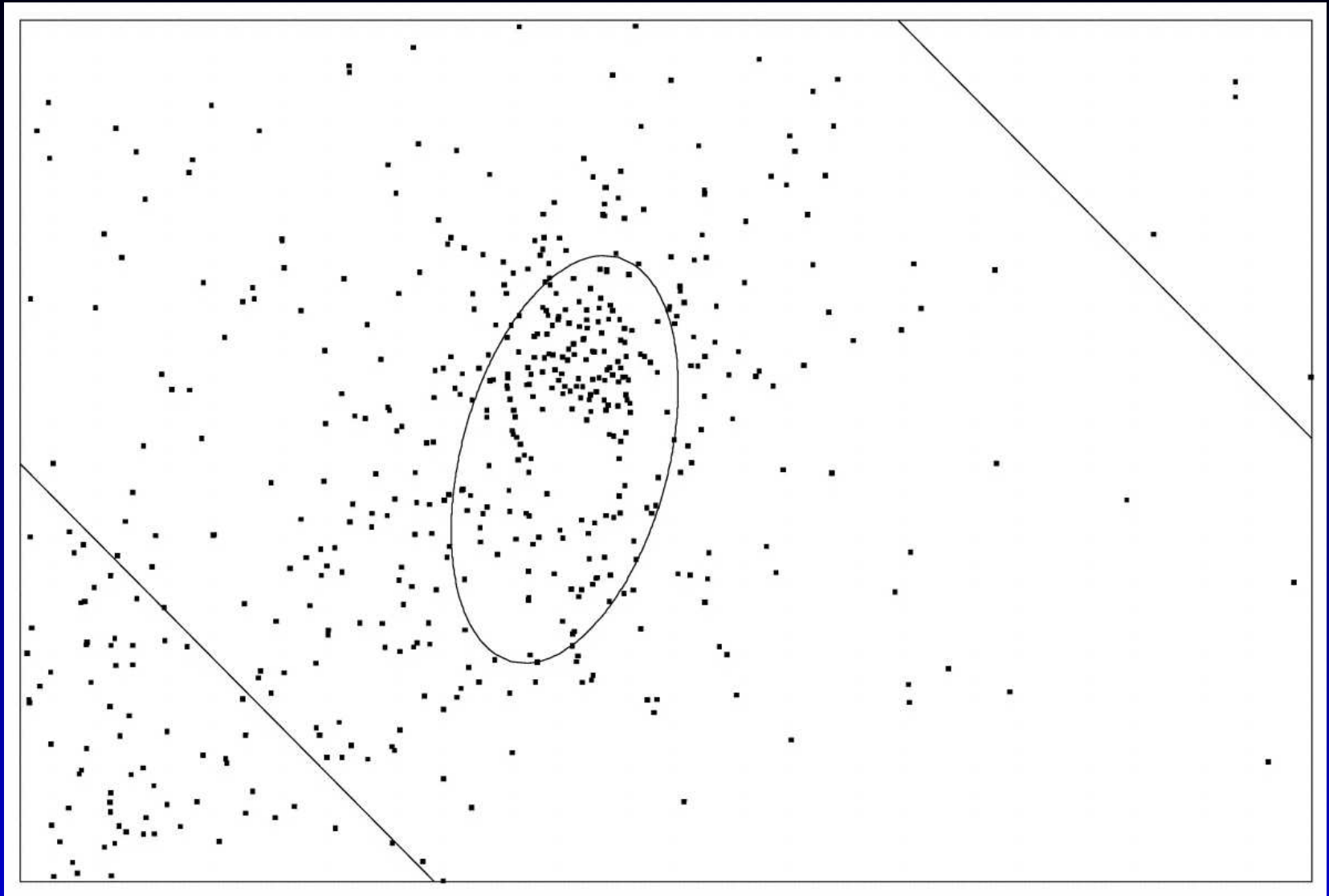
Name	$M_{\text{bol}}^{\text{max}}$	$M_{\text{bol}}^{\text{min}}$	$M_{\text{bol}}^{\text{mean}}$	spread	N_{all}	$N_{M_{\text{bol}} > -3.5}$
	(mag)	(mag)	(mag)	(mag)		
Sculptor	-4.49	-2.71	-3.22	0.57	8	7
Carina	-4.85	-3.14	-4.30	0.61	6	1
Draco	-3.62	-2.92	-3.27	0.35	3	2
UMinor	-2.90	-2.04	-2.60	0.33	6	6



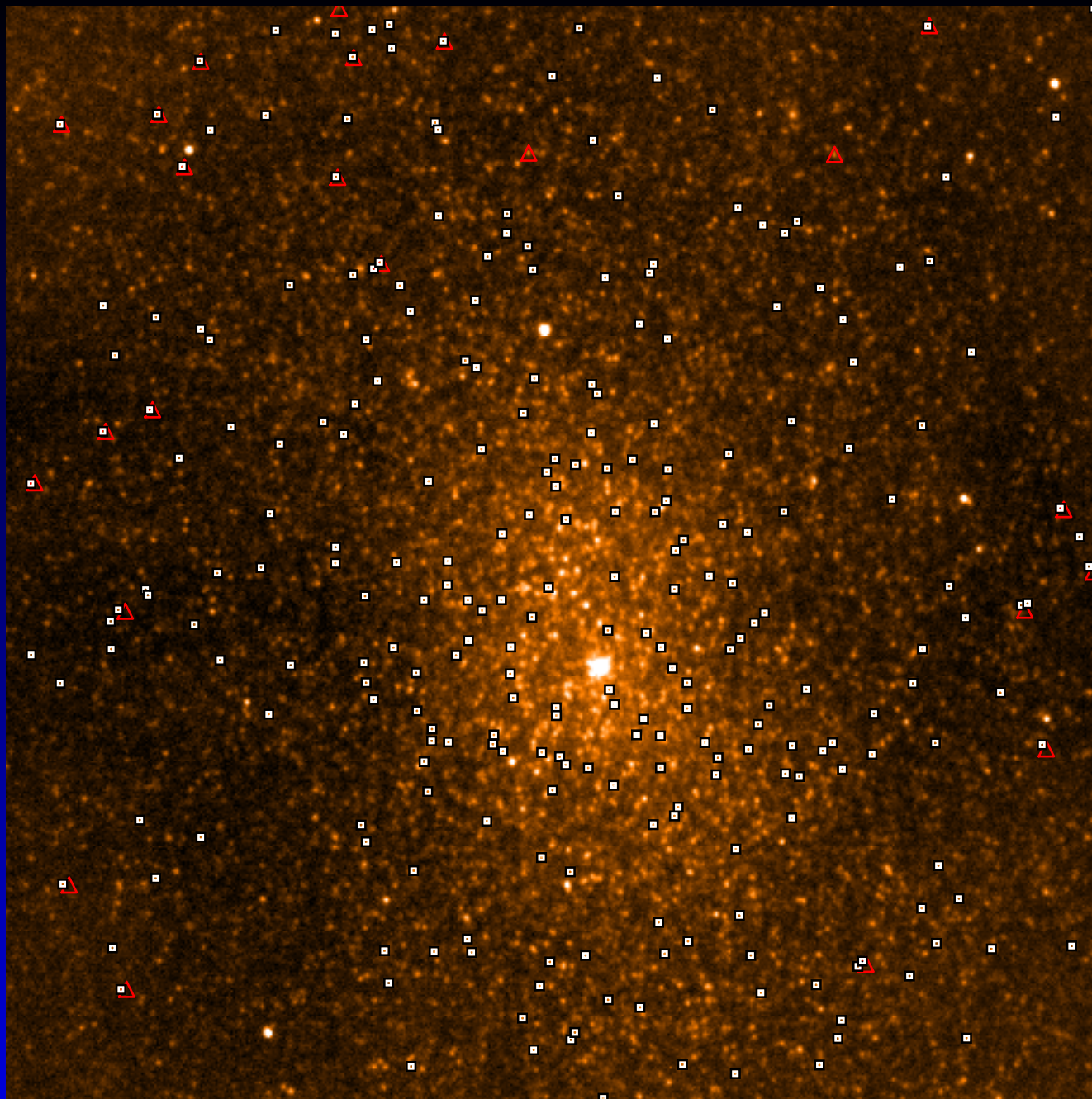




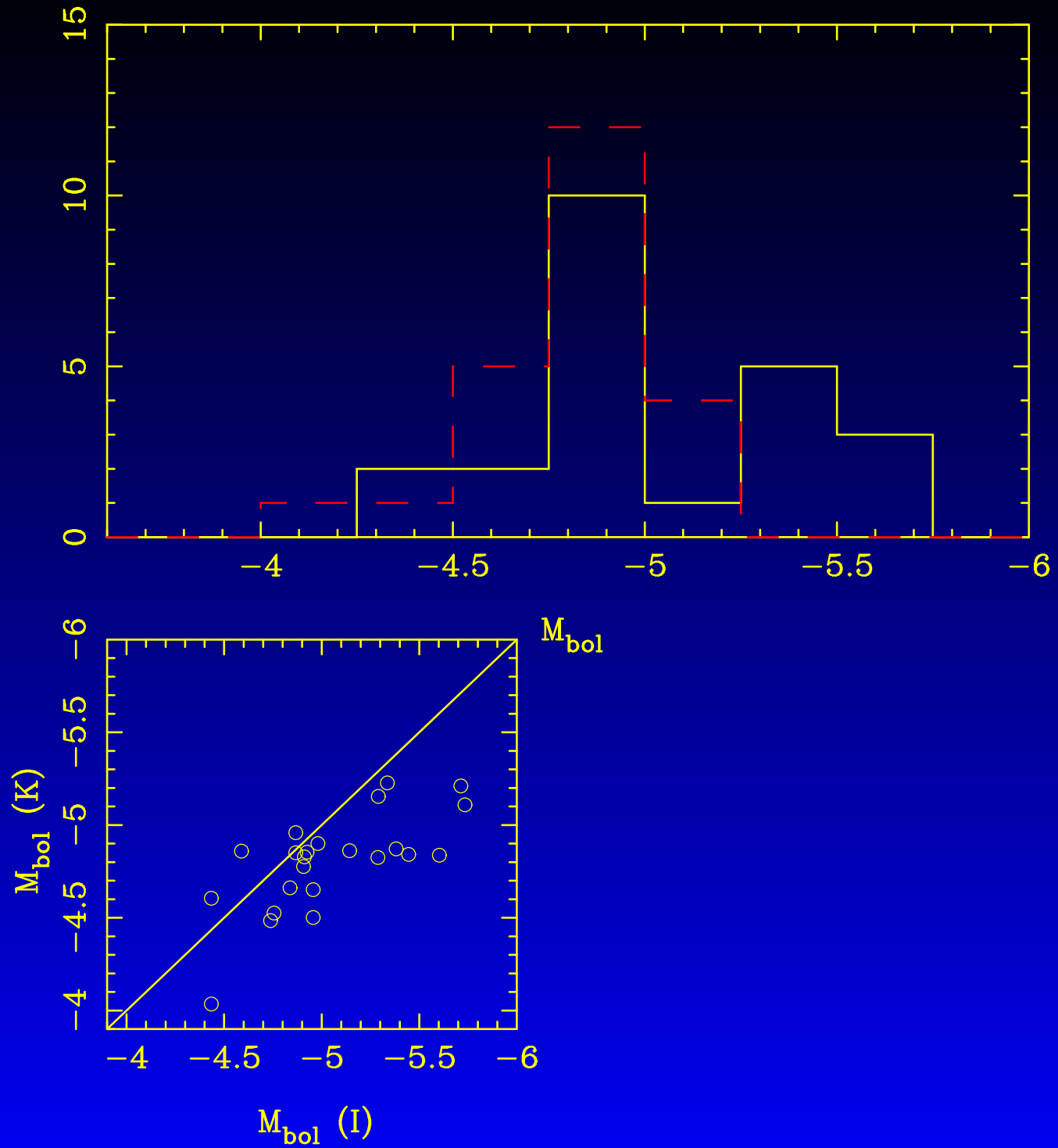




Demers et al. (2003) for NGC 205



NGC 205: 4' x 4' *K*-image; known C-stars (Δ)
($J - K$)₀ > 1.5 K ₀ < 17.2 (\square)



Future: narrow band imaging

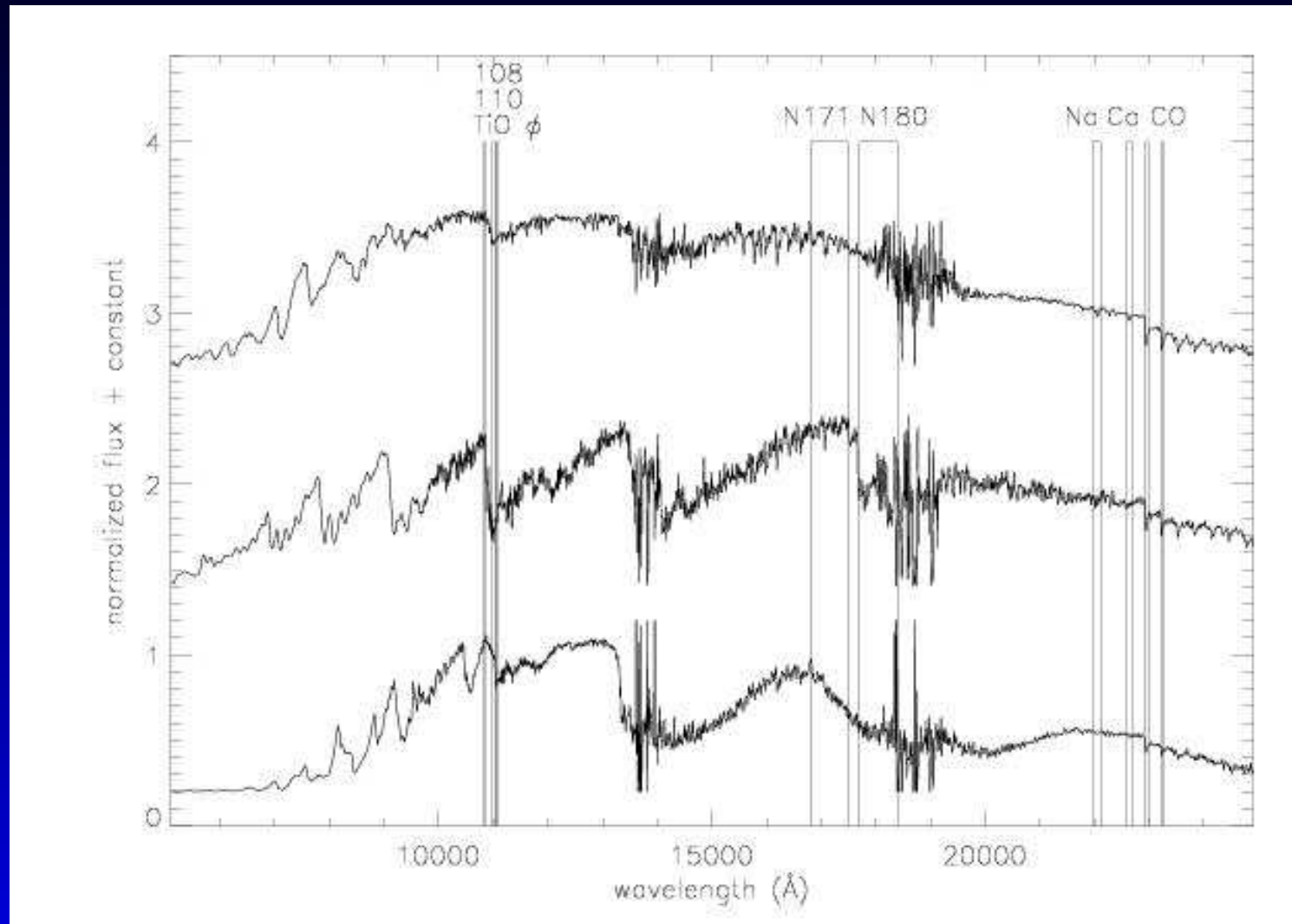
- (Groenewegen et al. :) Carina, Sculptor, Phoenix
- (Demers & Battinelli :) IC 10
- (Vienna group :)
And II (submitted), M32 (reduced), Leo I, Leo II,
Draco, Ursa Minor (acquired)

4.1m SOAR telescope, 5.5' FOV

Future: IR

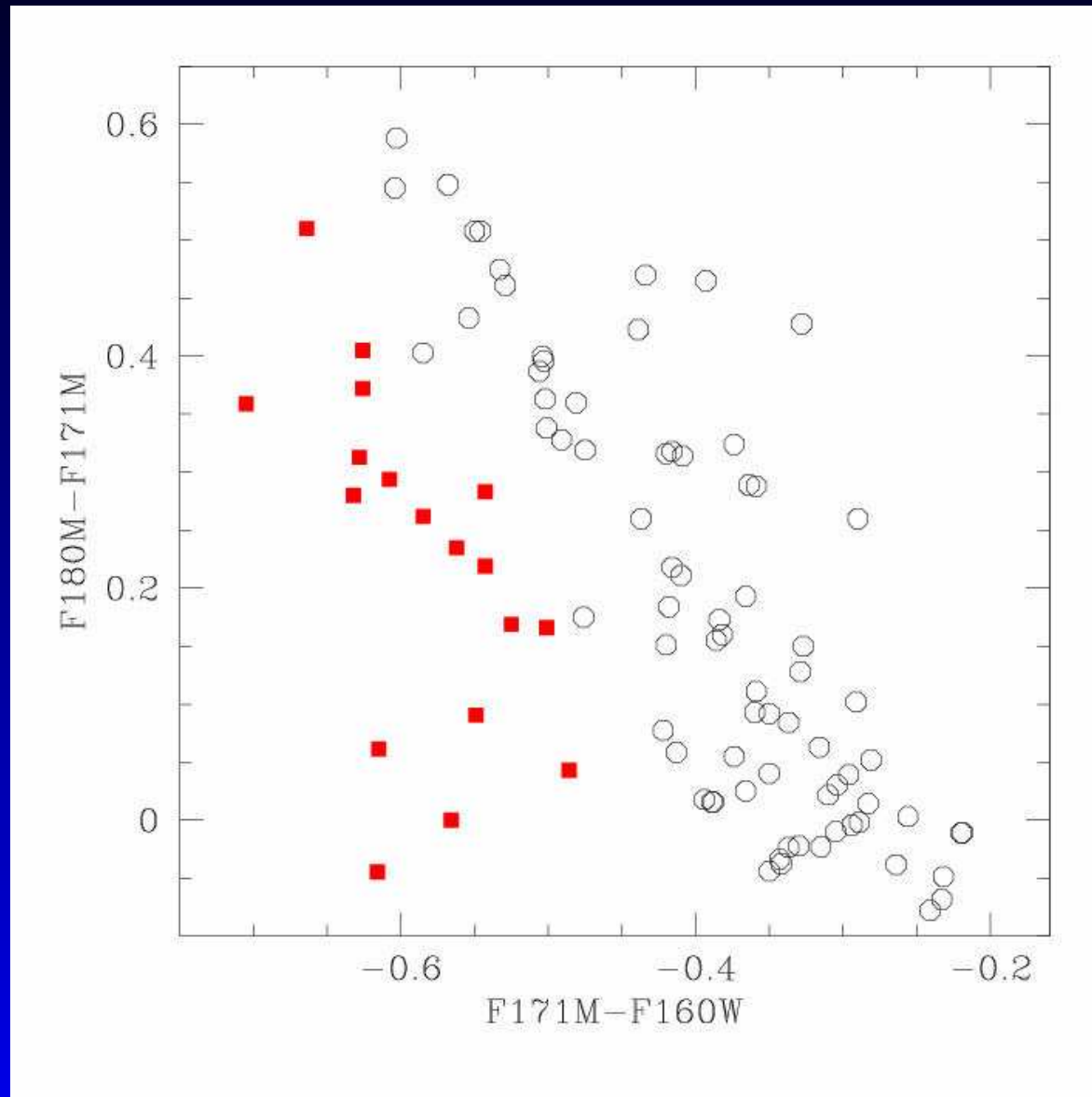
- Enrico Held/ SOFI: Fornax, Leo I, Leo II, Carina, Sculptor, Phoenix, Sextans
- Menzies et al. (SAAO+Japan)/ IRSF/ SIRIUS: Leo I, Fornax, (+all smaller LG)
- Cioni, Habing et al./ WHT/ INGRID: Leo A, Leo I, Leo II, Sex B, NGC 6822, Draco, NGC 147, NGC 185
- Rome+Montreal/ CTIO 1.5m/ CPAPIR: monitor NGC 6822

Narrow-band in the NIR



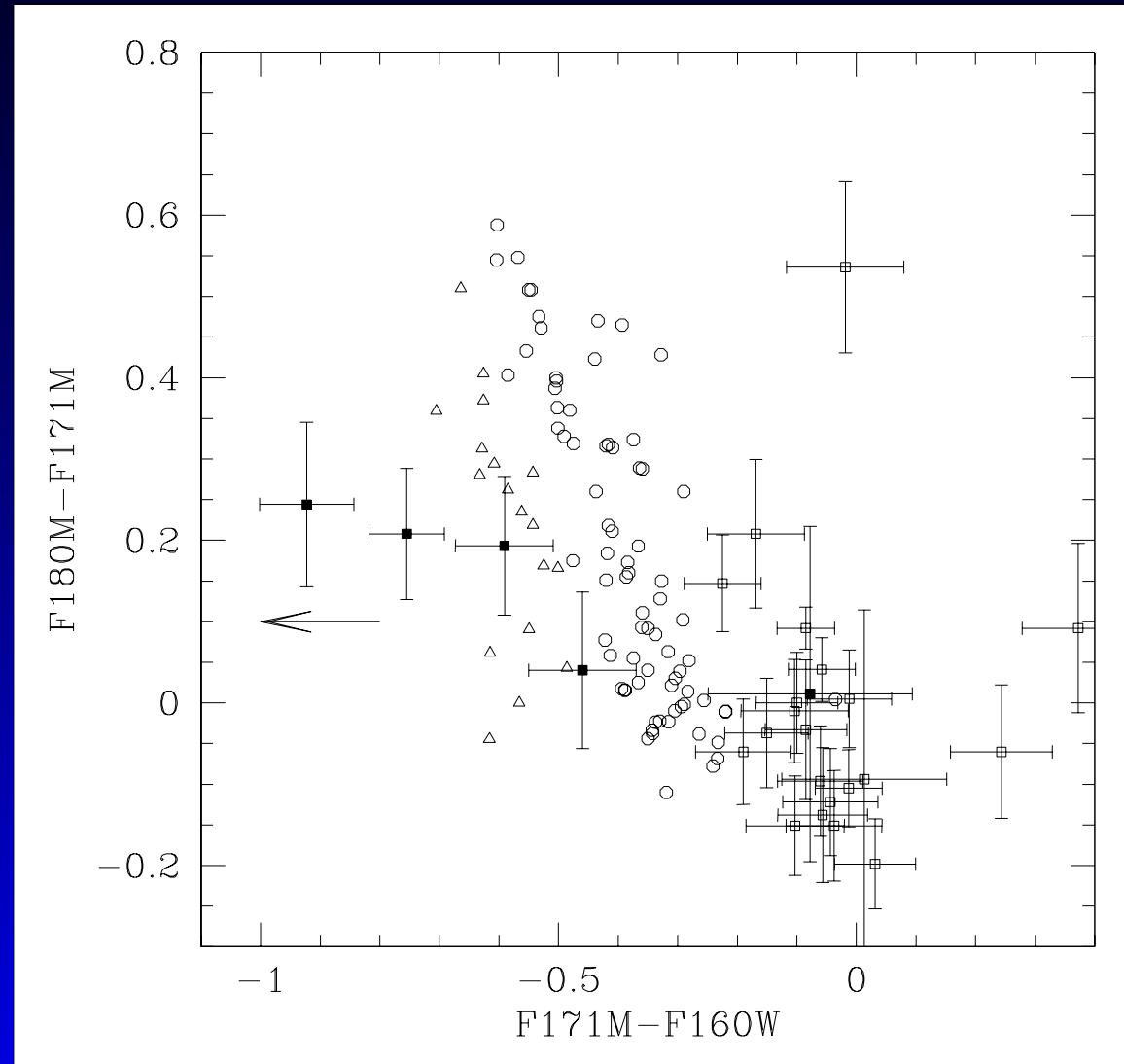
NICMOS filters; M-SG, C, M

Narrow-band in the NIR



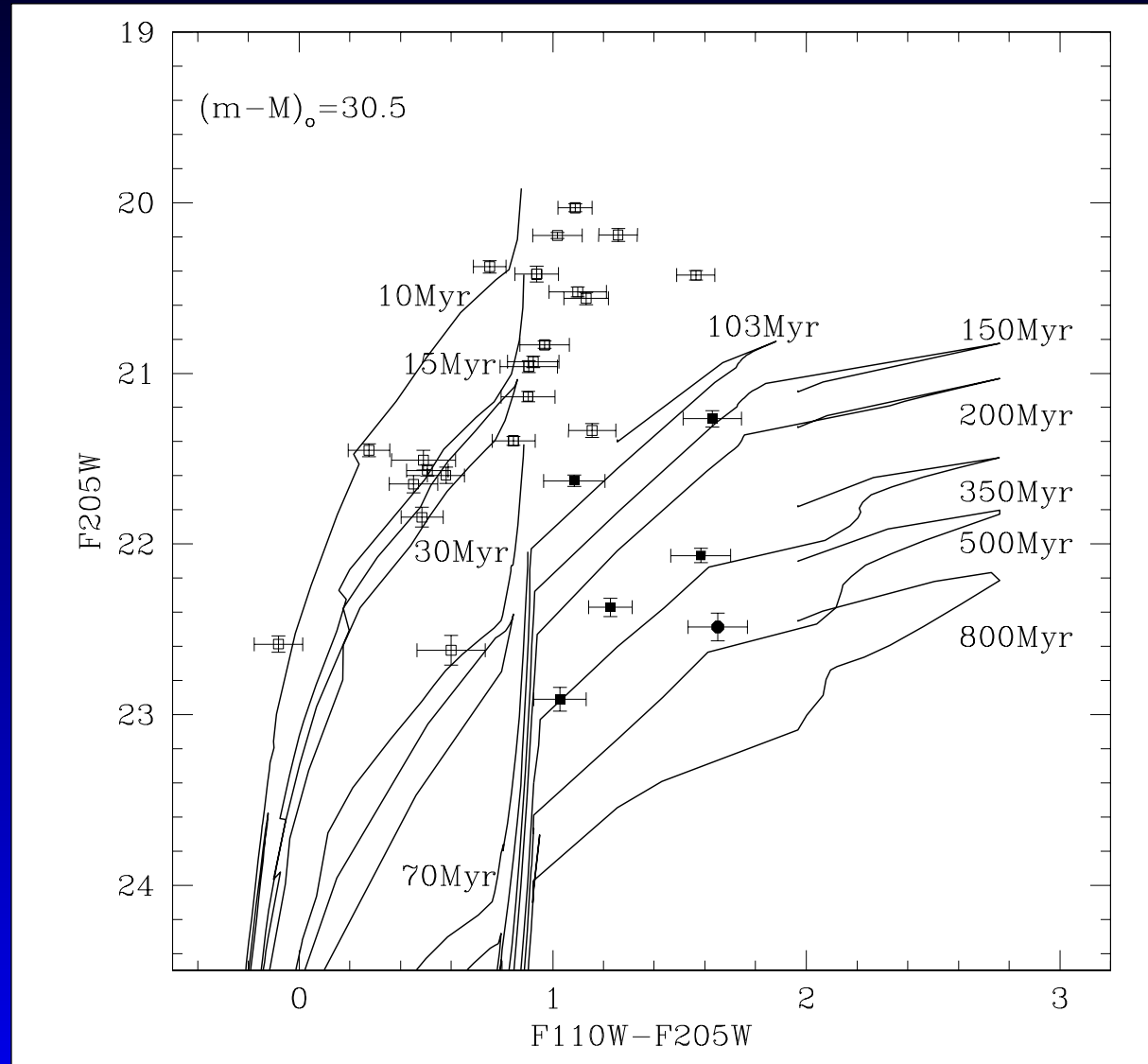
local sample: M (white circles), C (red squares)

Narrow-band in the NIR



I Zw 18

Narrow-band in the NIR



I Zw 18

Östlin & Mouhcine (2004)

HST 14''x 14'' [Fe/H]= -1.7 DM= 30.5 (!!)

5 C-stars, 1 M-type AGB, 20 SG

$$J - K = 1.0 \quad K = 22.8 \quad M_{\text{bol}} = -5.0$$

$$J - K = 1.6 \quad K = 21.4 \quad M_{\text{bol}} = -6.1$$

Theory

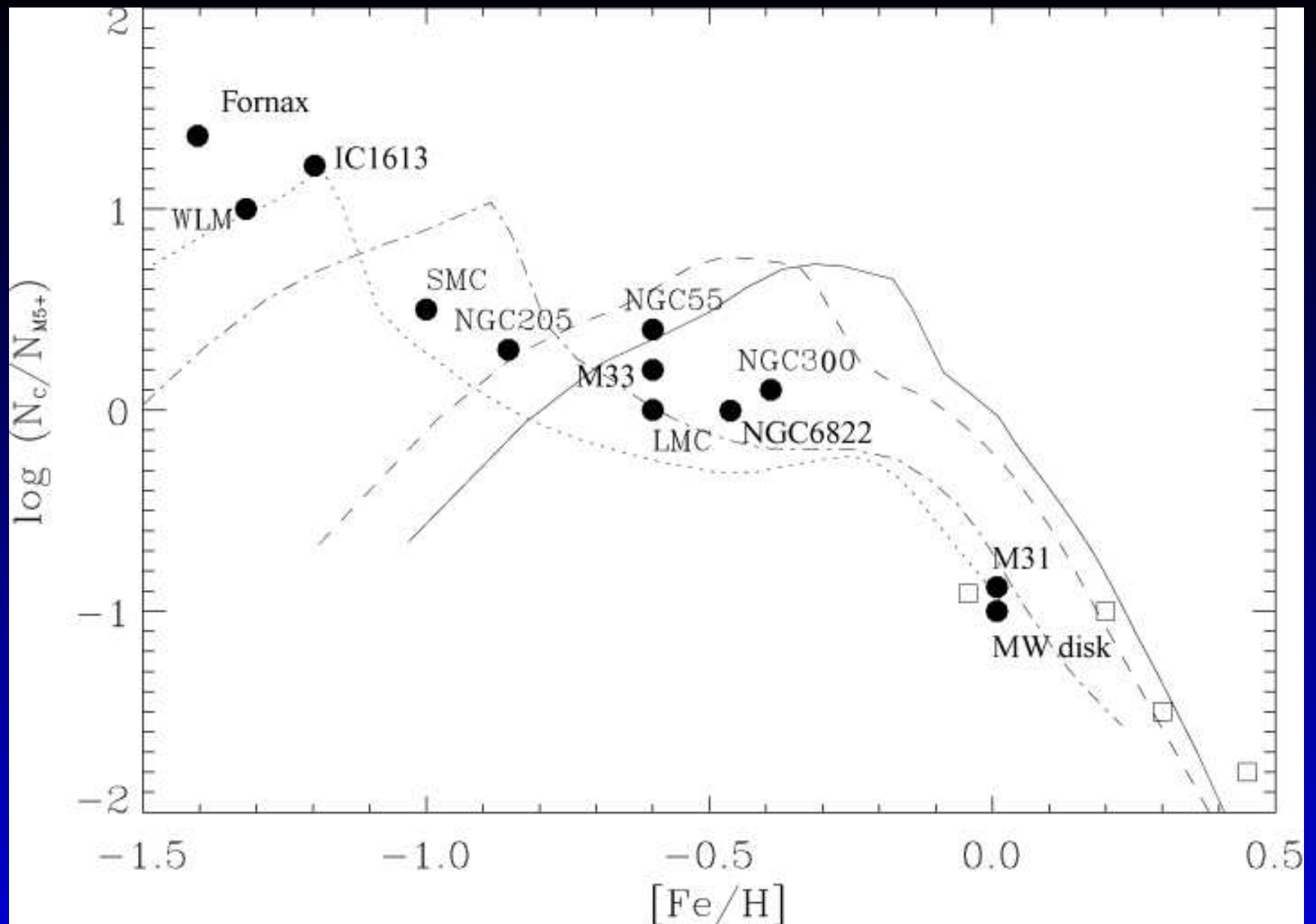
- Mouhcine & Lançon (2003)

Evolutionary population synthesis models,
including chemical evolution.

Semi-analytical treatment of the third dredge-up,
with efficiency parameters set to values that fit
the LMC carbon star LF.

Assume typical SFRs, characteristic of Sa, Sb, Sc
and Irr type galaxies.

(Sa = solid ; dashed = Sb ; dot-dash = Sc ; dot = Irr)



Mouhcine & Lançon (2003)
 [data points from Groenewegen (1999) !]

Conclusions

Narrow-band filter technique most efficient

- At the moment limited to $\lesssim 1$ Mpc
(NGC 3109 1.3Mpc CFHT $0.7''$: $6.0h I \sim 23.5$)
- Different groups adopt different selection criteria
- Data on the M-stars often not published

Infra-red view

- Nearby galaxies: MOS of objects with $J - K \gtrsim 1.5$
- Narrow-band filters in NIR
- Dust & mass loss at low-metallicity (!)

Conclusions

Theory

- First attempts have been made
- Fit specific galaxies using SFR determined independently: feedback on third dredge-up efficiency

THE END