AGB stars in the Local Group, and beyond

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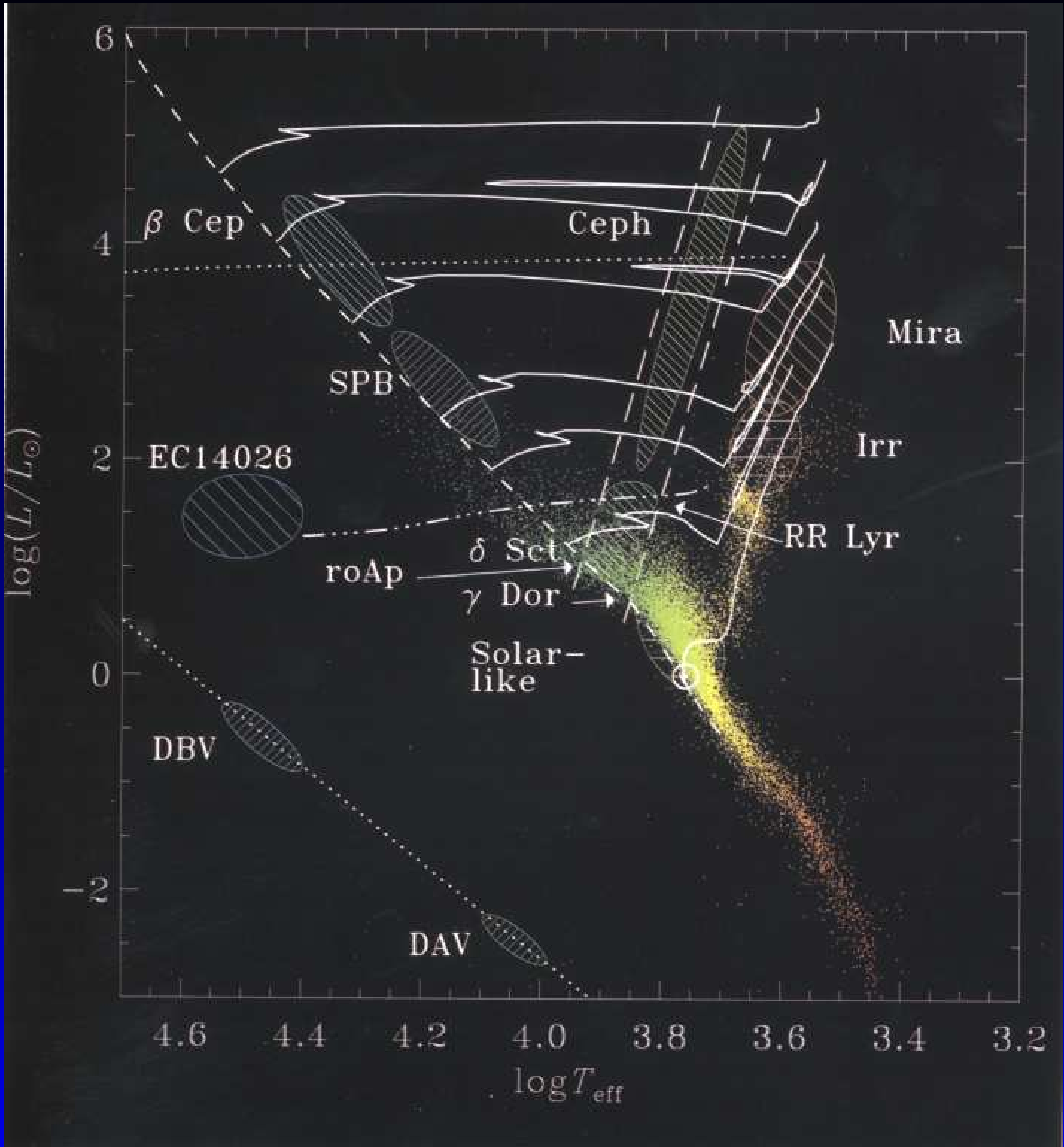
Overview

- 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_{\rm initial} \gtrsim$1.5 $M_\odot$ (solar),
$M_{\rm initial} \gtrsim$1.3 $M_\odot$ (LMC)

Late-type stars

- Carbon stars (C/O ≥ 1)

  N-type

  "infrared carbon stars"

  R-type

  CH-type

  carbon dwarfs (polution by present-day WD)

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

  "intrinsic"

  "extrinsic" (polution 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 (polution by present-day WD)

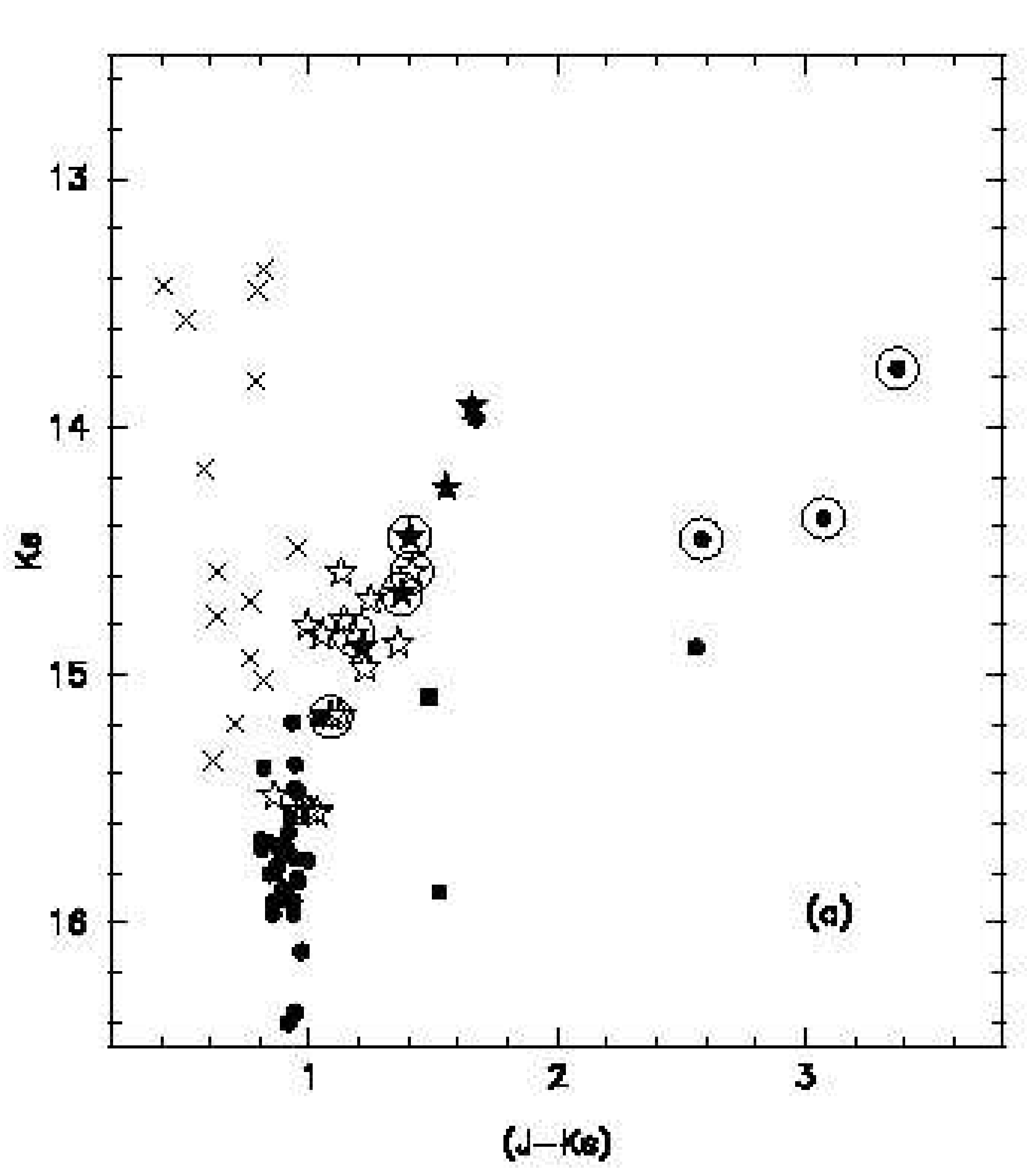
In general:
Stars which show Tc are presently on the AGB

How to identify late-type stars ?

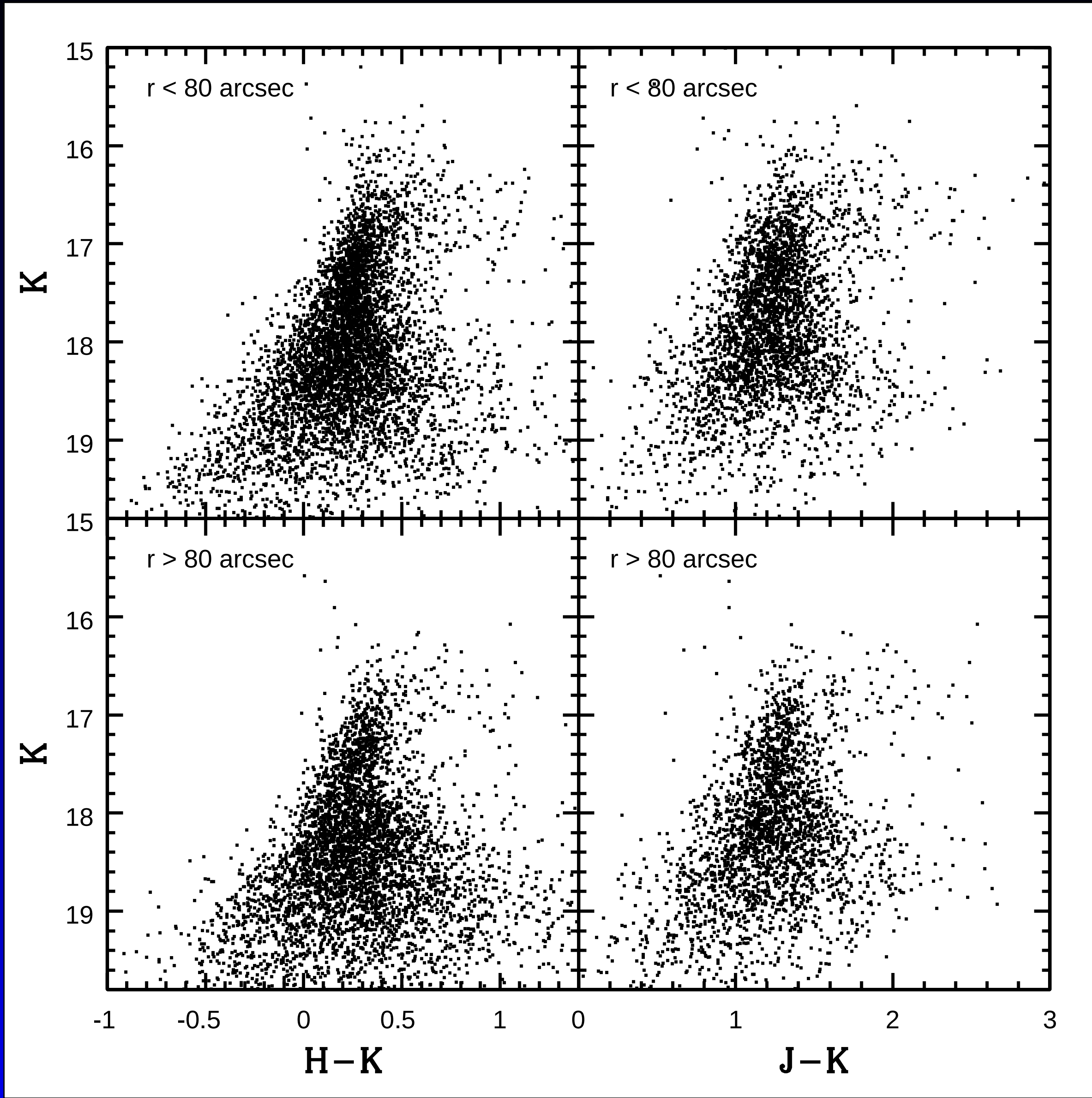
- Infra-red broadband photometry

  Disadvantage:
  Candidates only,
  $(J - K)$ colour is often used as discriminant M/C

  Advantage:
  Very red colours traces different population



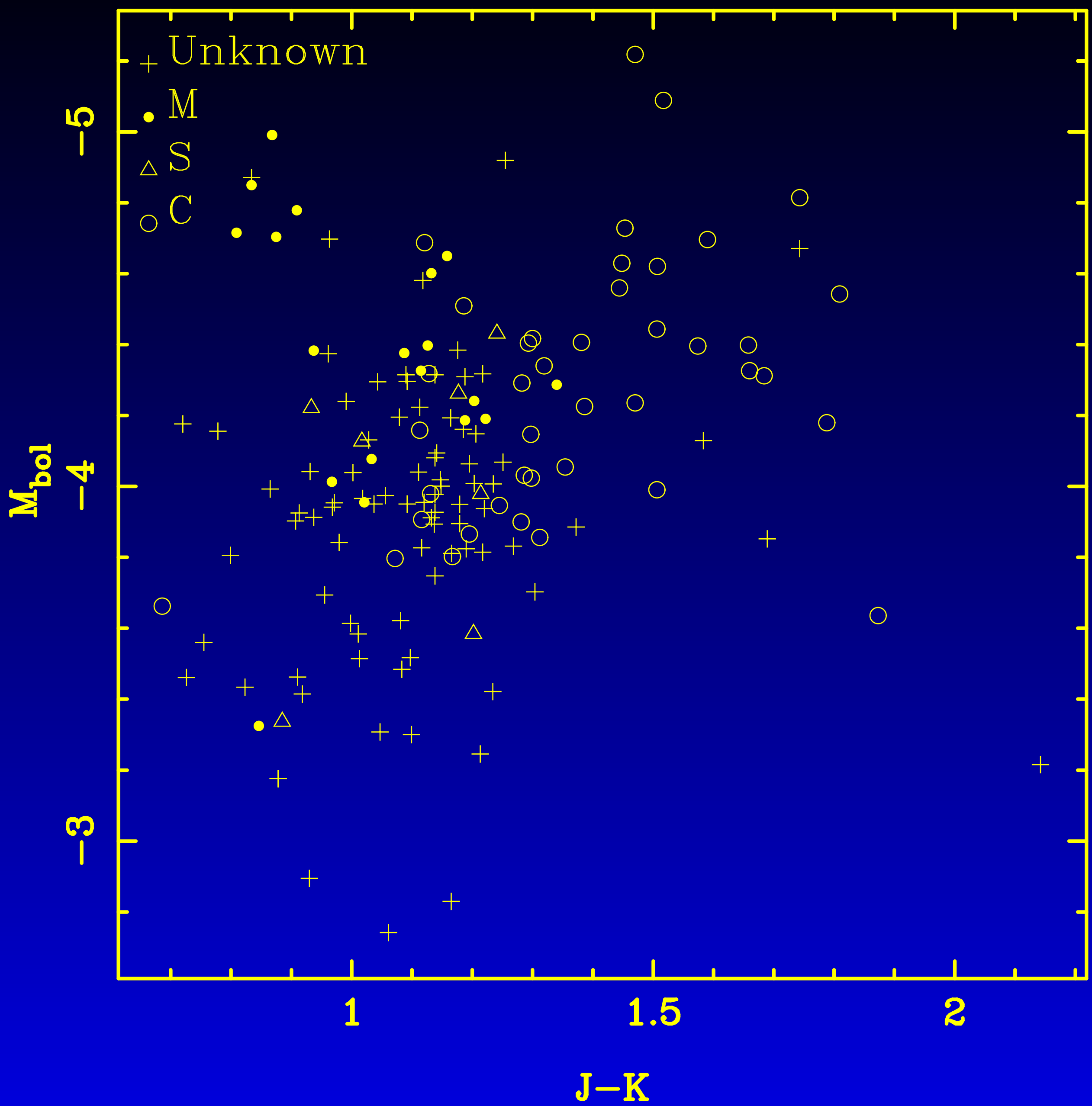
Menzies et al. (2002) for Leo I



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 $M_{\rm K}$-range, SIMBAD

2MASS: candidate infrared AGB stars

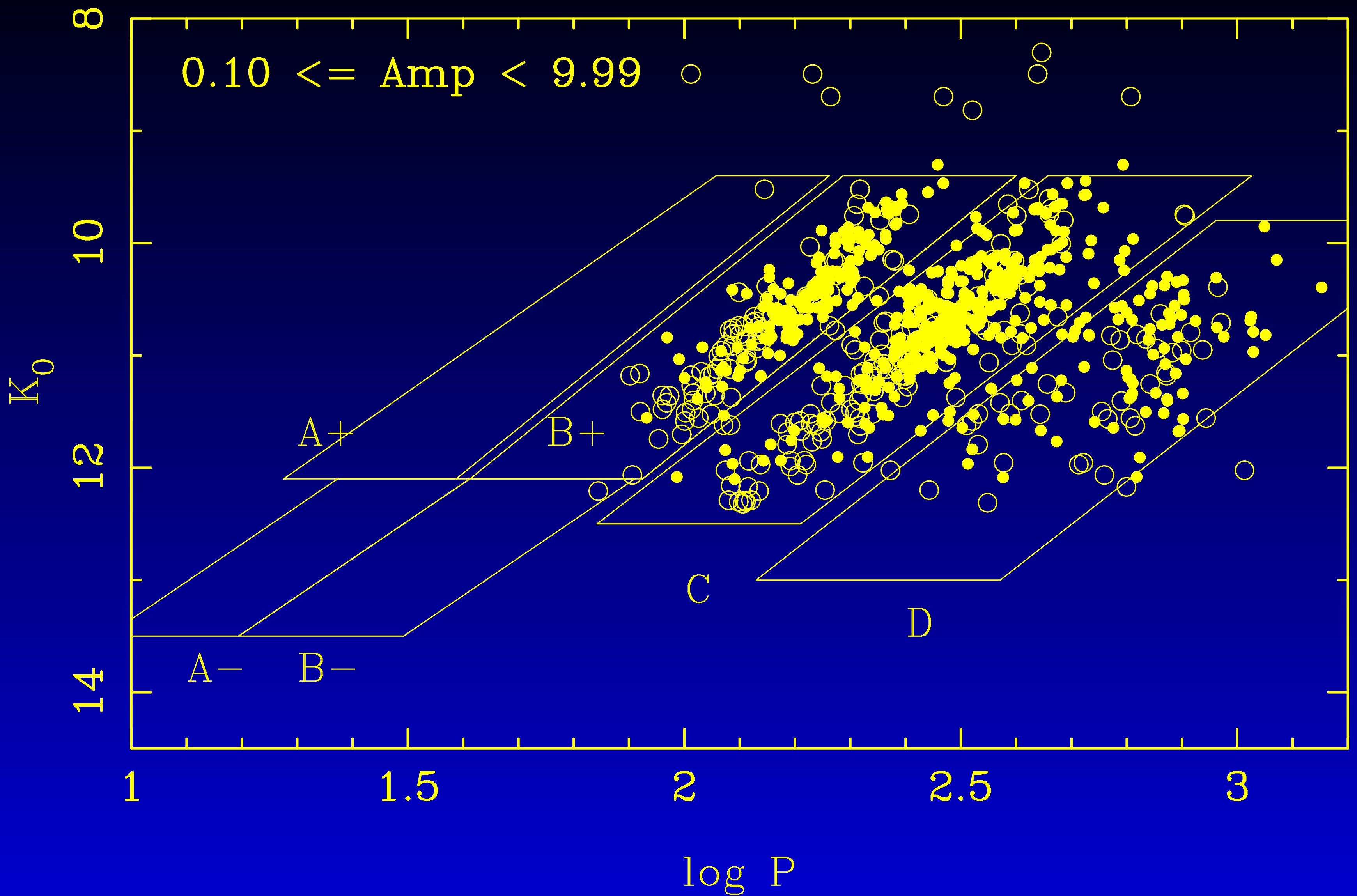
Name	D (kpc)	N_{2mass}	N_C
Ursa Minor	69	8	7
Sculptor	79	8	8
Draco	82	6	6
Sextans	86	10	(0)
Carina	100	6	11
Fornax	138	34	104
Leo II	205	1	8
Leo I	250	2	23
NGC 6822	490	6	904
LGS 3	620	1	?
IC 10	660	9	?
IC 1613	720	3	195
NGC 147	755	1	288
And I	790	1	0
Leo A	800	2	?
Tucana	870	1	0

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

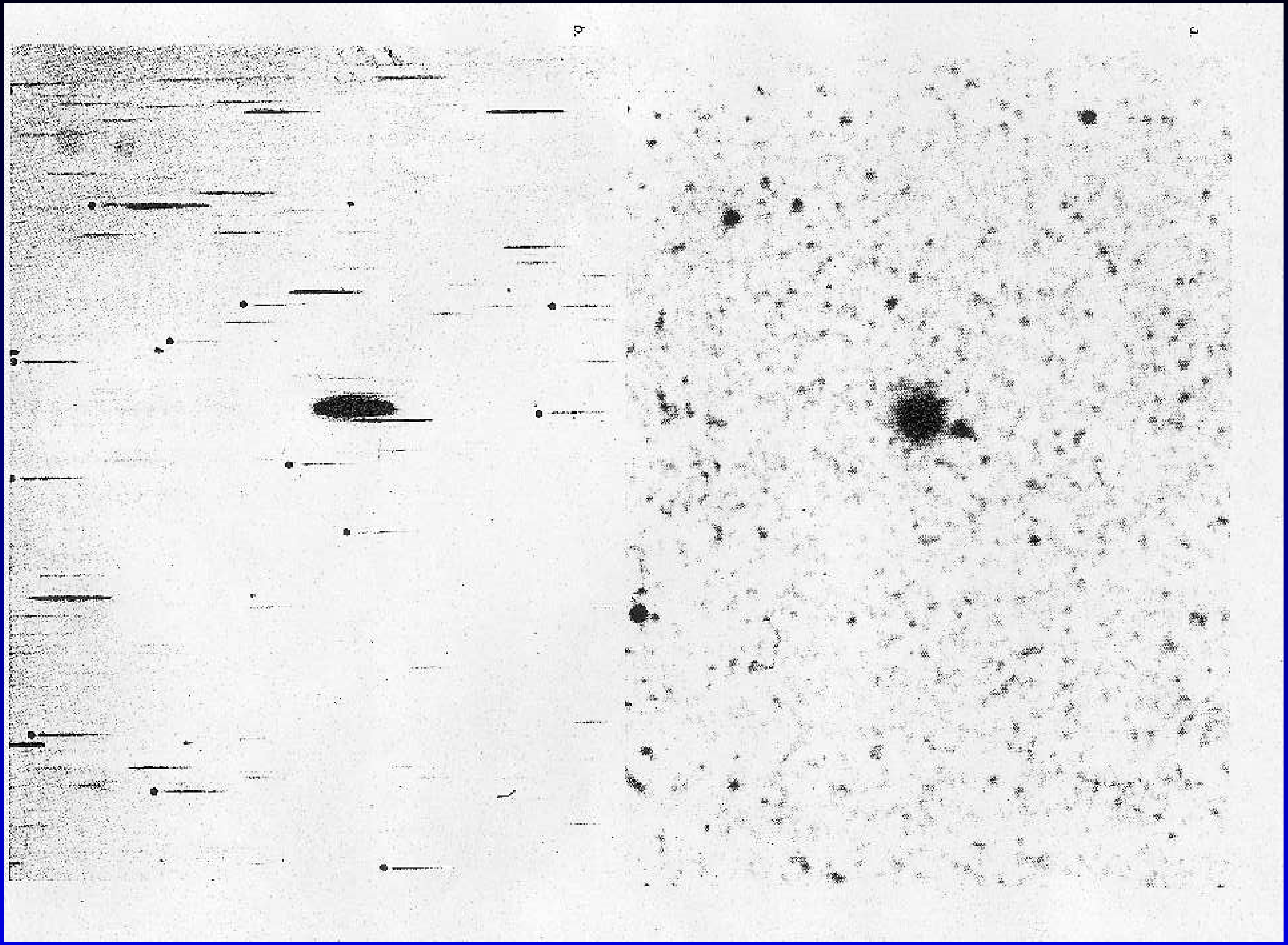
- MCs
  (Wood, Noda, Lebzelter, Cioni, Ita, Kiss, Glass)
- Bersier & Wood (2002):
  85 LPV candidates in Fornax
- Snigula et al. (2003):
  16 / 5 LPV candidates in Leo A / GR 8
- Gallart et al. (2004):
  6 LPV candidates in Phoenix
- Rejkuba (2004):
  240 well defined Miras in NGC 5128

How to identify late-type stars ?

- GRENS, GRISMS

  Azzopardi and Westerlund

  CN bands near 8000 Å
  C_2 bands 4737, 5165 Å
  disadvantage: crowding, sensitivity



Westerlund 1978

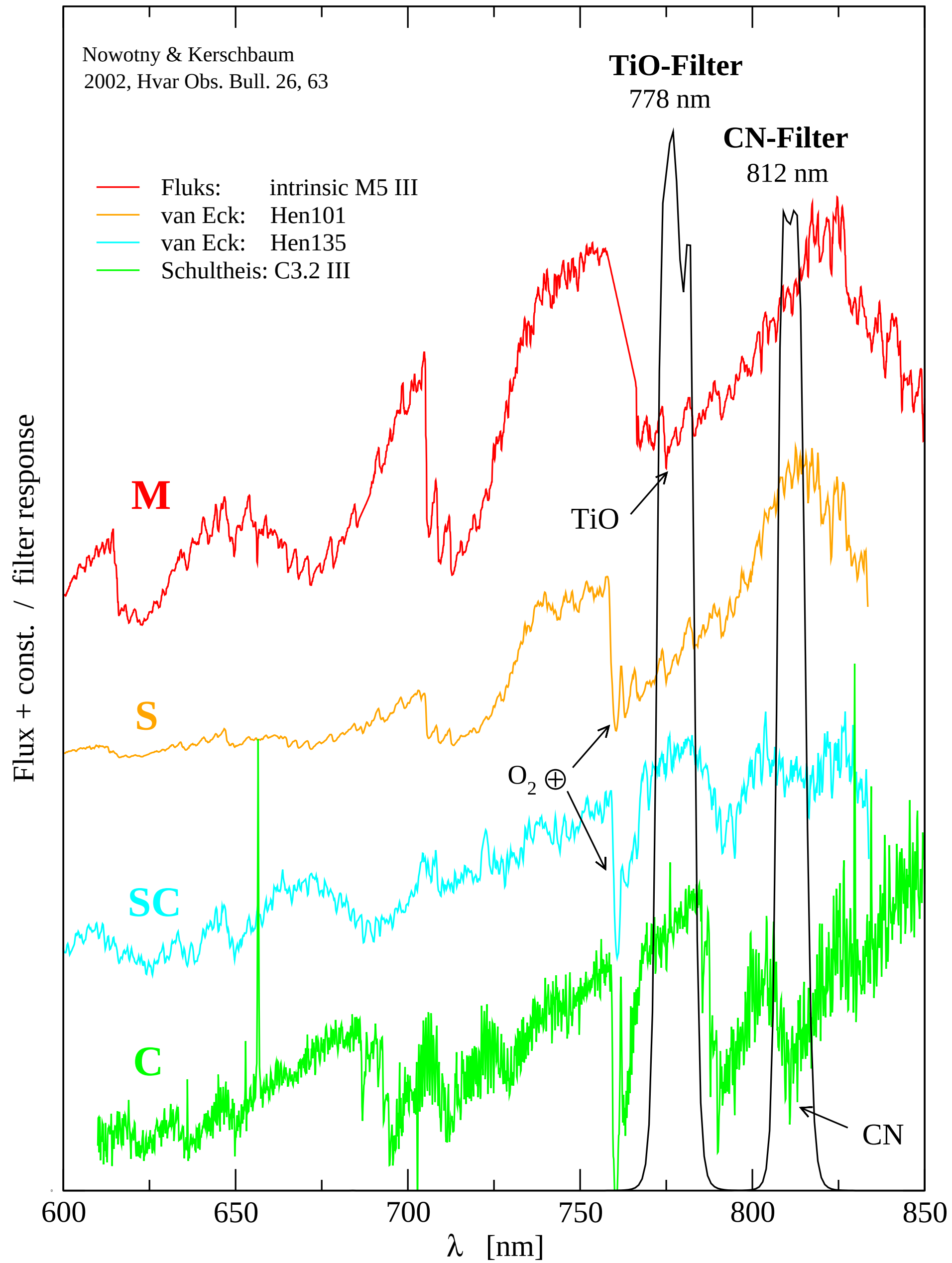
How to identify late-type stars ?

- Narrow-band filters

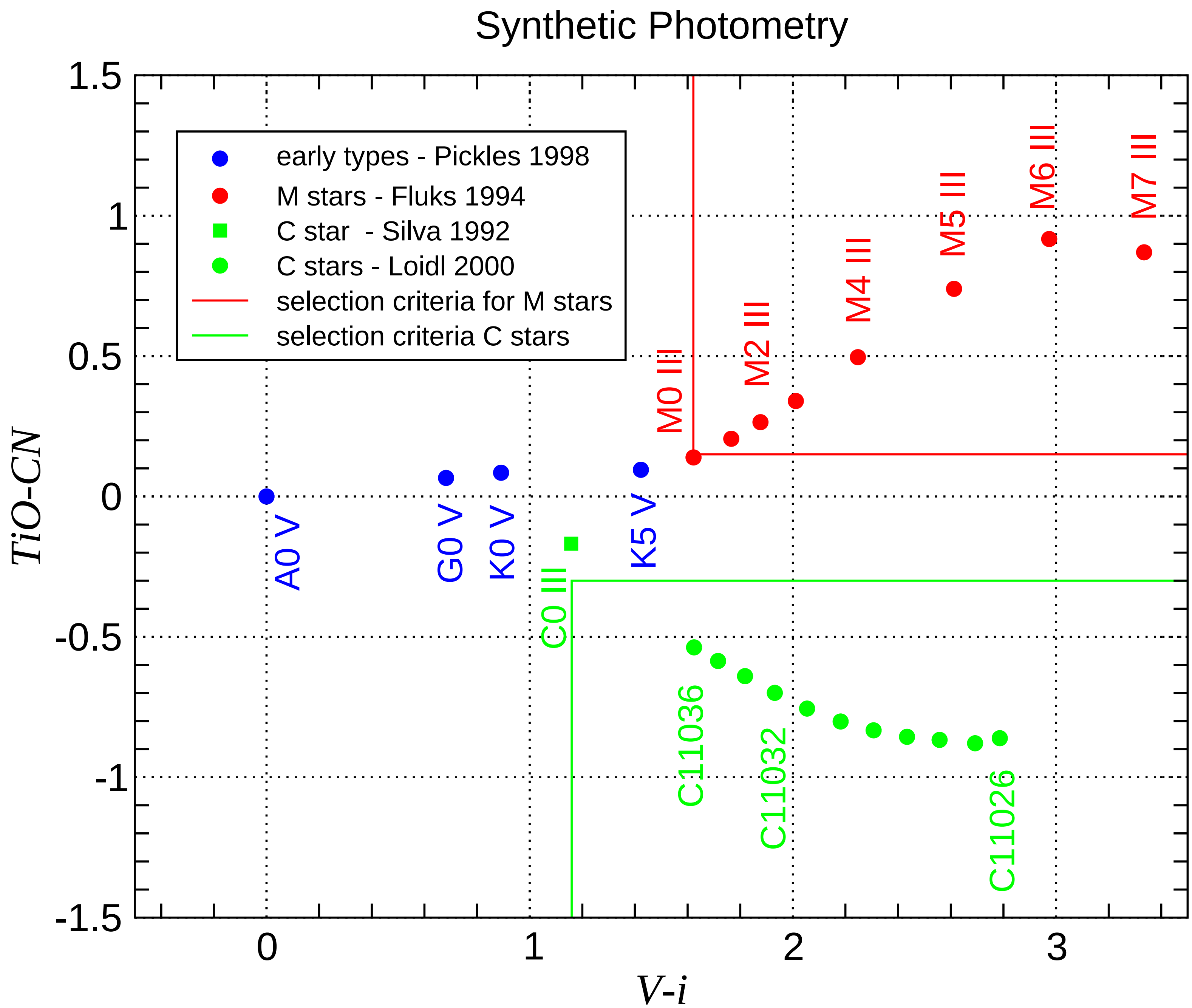
  Richer et al. (1984); Aaronson et al. (1984)
  broad-band V,R,I + narrow-band 7800, 8100

  advantage: spectroscopic identification
  disadvantage: foreground M-stars

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



Nowotny & Kerschbaum 2002



Nowotny & Kerschbaum 2002

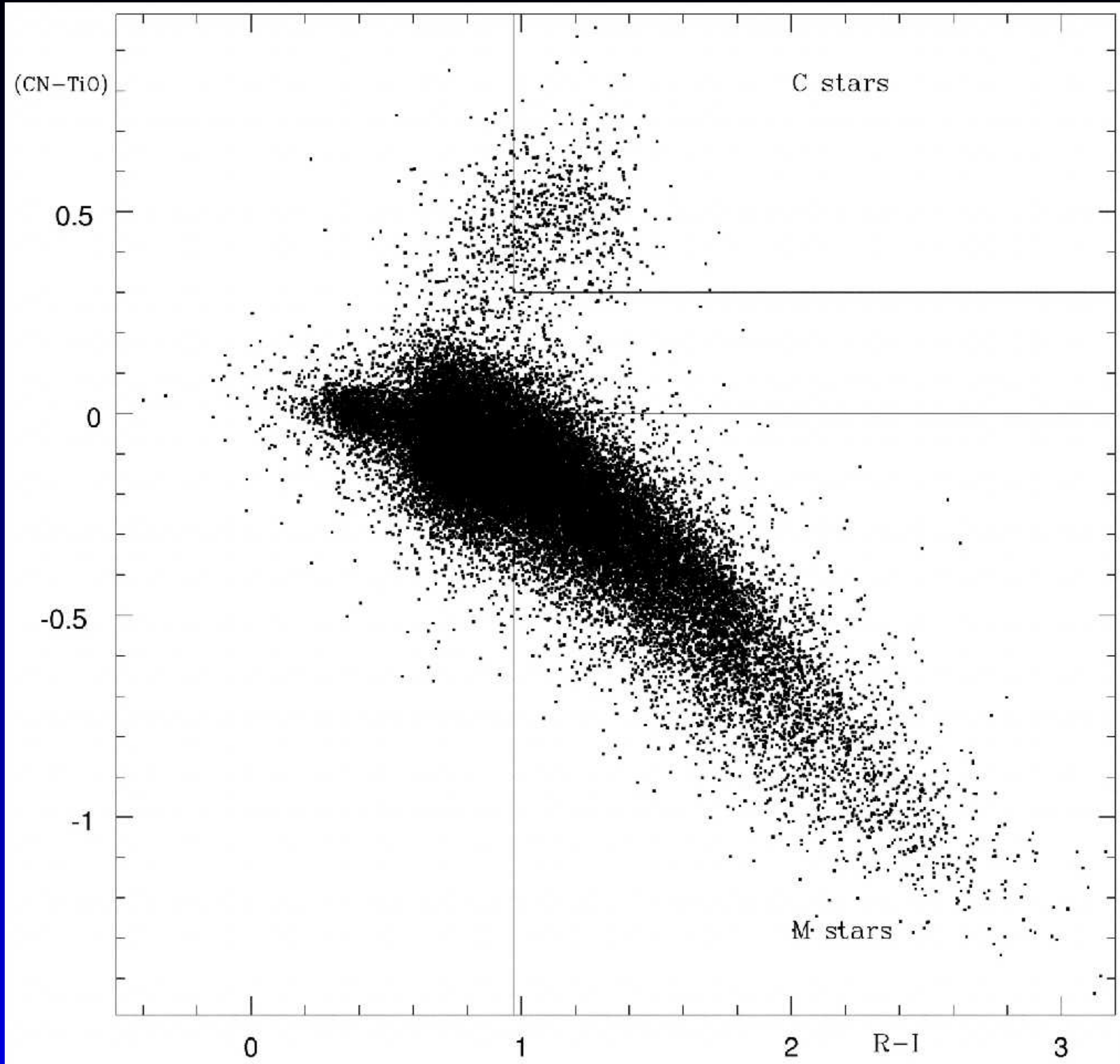
Recent surveys (> 2002)

- 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



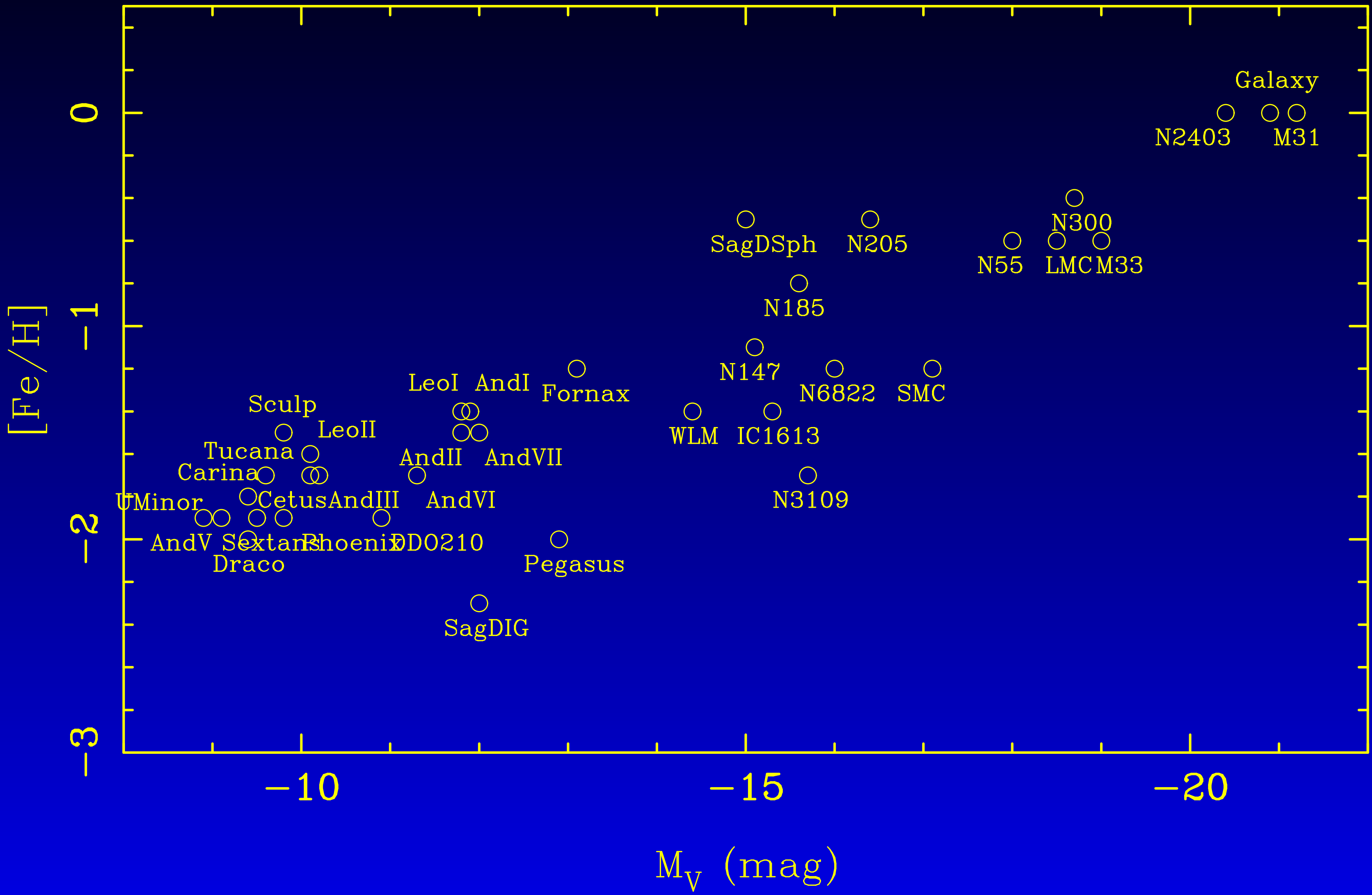
Demers et al. (2003) for NGC 205

Name	D (kpc)	M_V (mag)	[Fe/H]	N_C	Area (kpc^2)	N_M
M31	770	–21.2	0.0	243	12.3	789 (5+)
Galaxy		–20.9	0.0	81	1.00	C/M ≈ 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+)

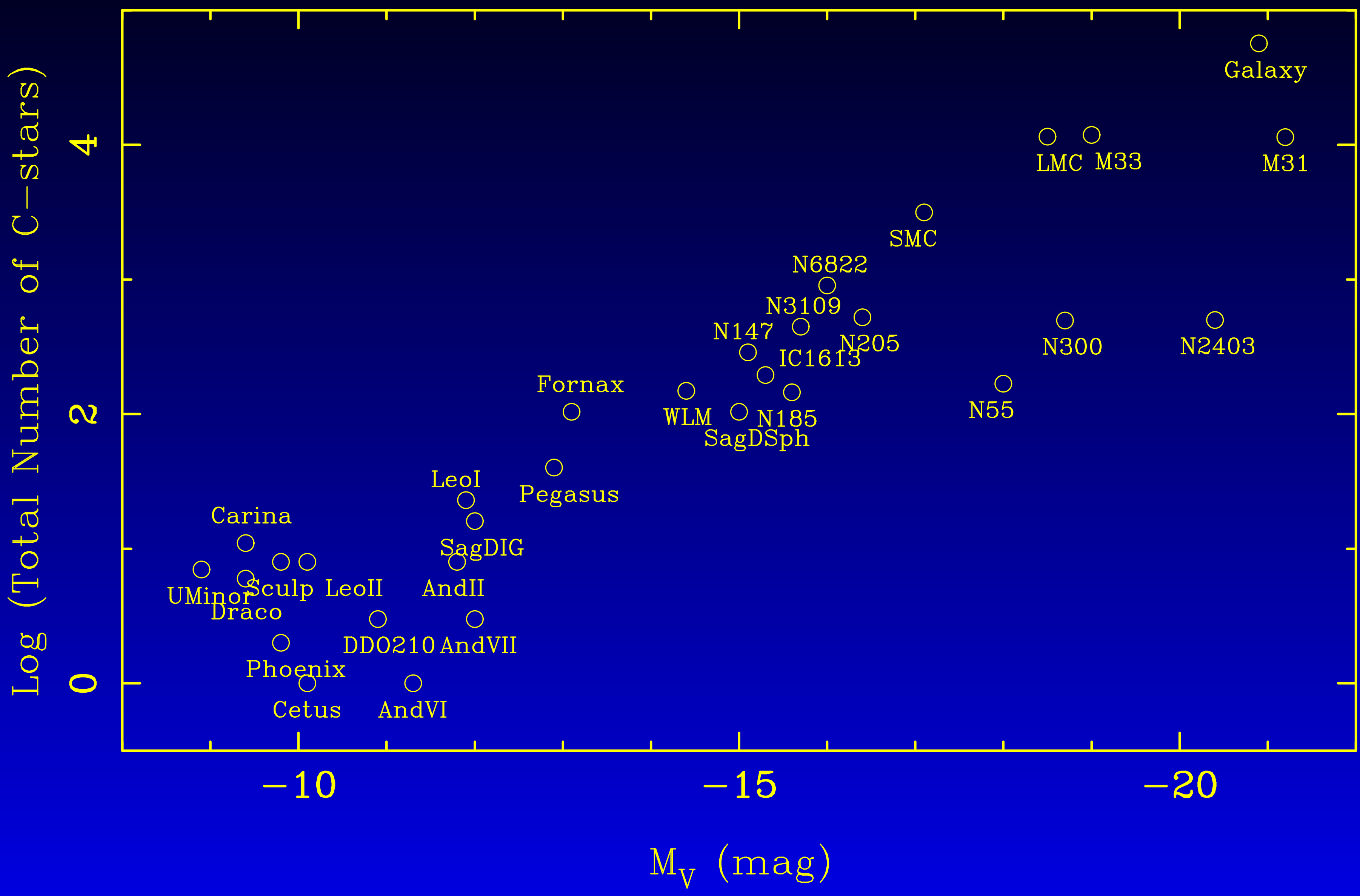
Name	D (kpc)	M_V (mag)	[Fe/H]	N_C	Area (kpc^2)	N_M
IC 1613	715	–15.3	–1.4	195	7.8	35 (5+), 300 (0+)
NGC 147	755	–15.1	–1.1	288	25.	1200 (0+)
SagDSph	28	–15.0	–0.5	26	7.2	
WLM	930	–14.4	–1.5	14	0.28	0 (5+), 6 (0+)
(new)				149	17.0	12 (0+)
Fornax	138	–13.1	–1.2	104	1.35	4 (5+), 25 (2+)
Pegasus	760	–12.9	–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 (kpc)	M_V (mag)	[Fe/H]	N_C	Area (kpc^2)	N_M
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	

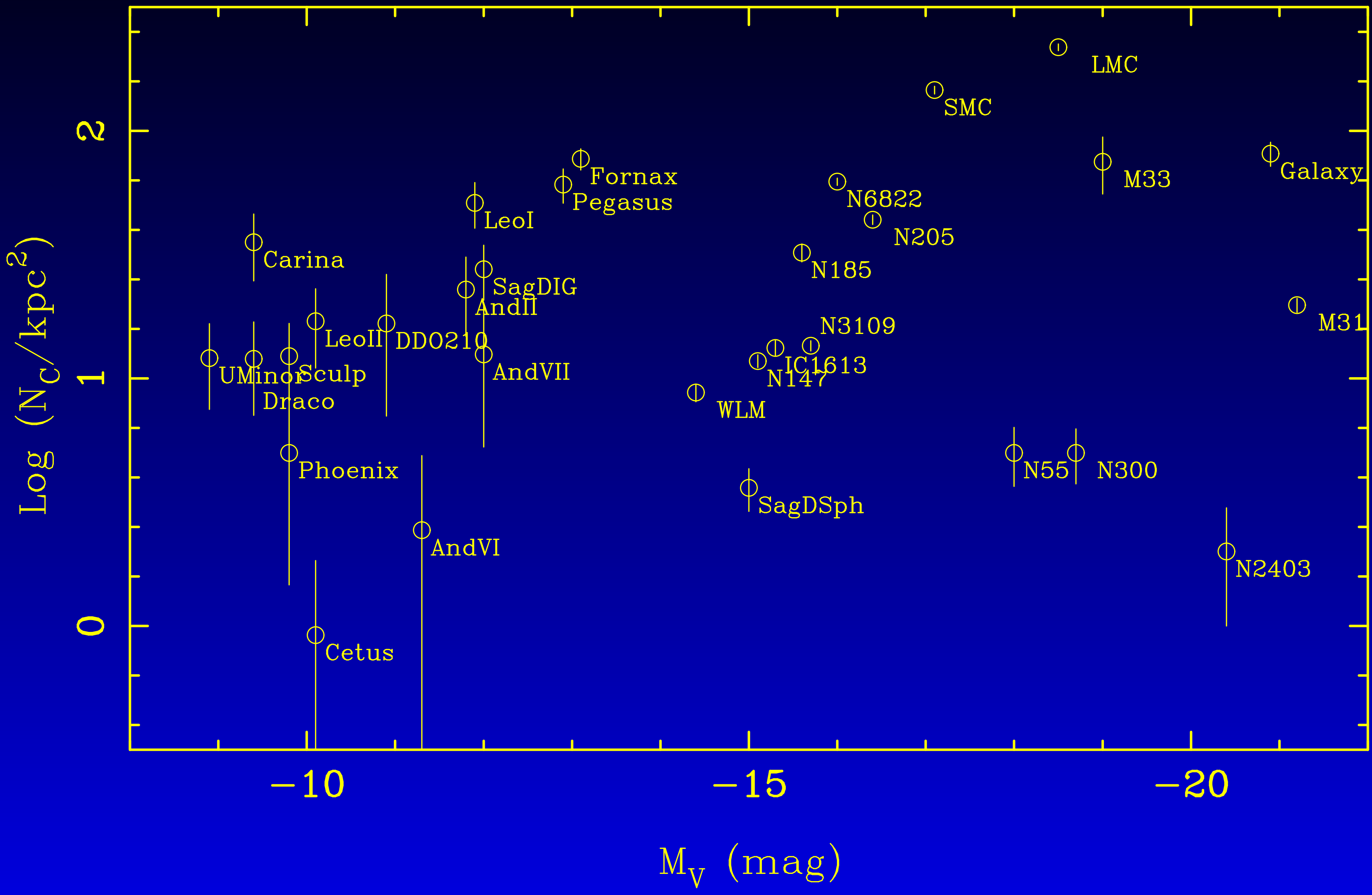
Name	D (kpc)	M_V (mag)	[Fe/H]	N_C	Area (kpc^2)	N_M
Carina	94	–9.4	–1.8	11	0.31	
Ursa Minor	69	–8.9	–1.9	7	0.58	
NGC 2403	3390	–20.4	0.0	4	2.0	7 (0+)
NGC 300	2170	–18.7	–0.4	16	3.2	23 (0+), 6 (5+)
NGC 55	1480	–18.0	–0.6	14	2.8	6 (5+)



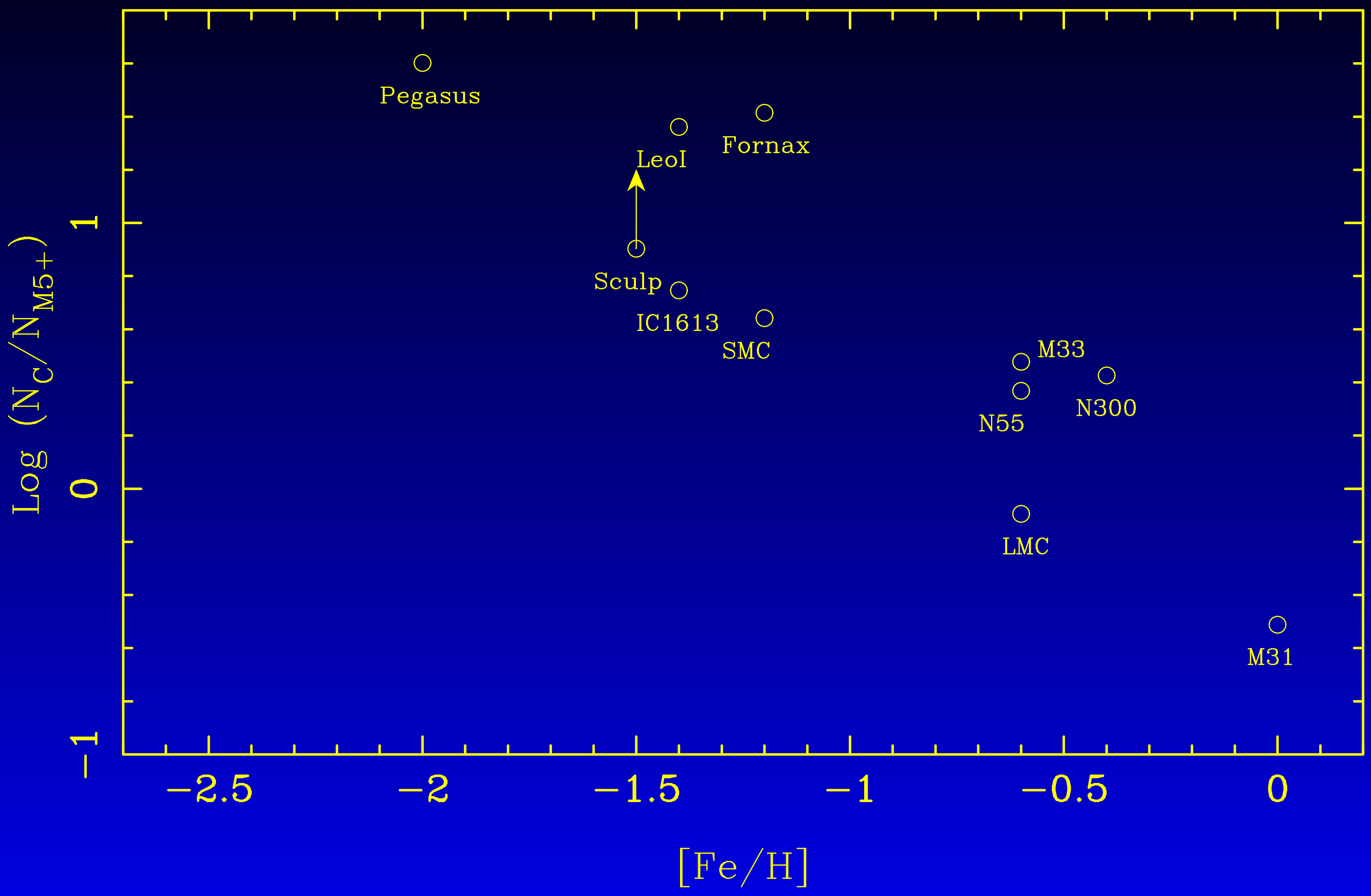
[Fe/H]
MV (mag)
0
−1
−2
−3
−10
−15
−20
Galaxy
N2403
M31
N300
SagDSph
N205
N55
LMC
M33
N185
N147
N6822
SMC
LeoI
AndI
Fornax
Sculp
LeoII
WLM
IC1613
Tucana
AndII
AndVII
Carina
N3109
UMinor
Cetus
AndIII
AndVI
AndV
Sextans
Phoenix
DDO210
Pegasus
Draco
SagDIG

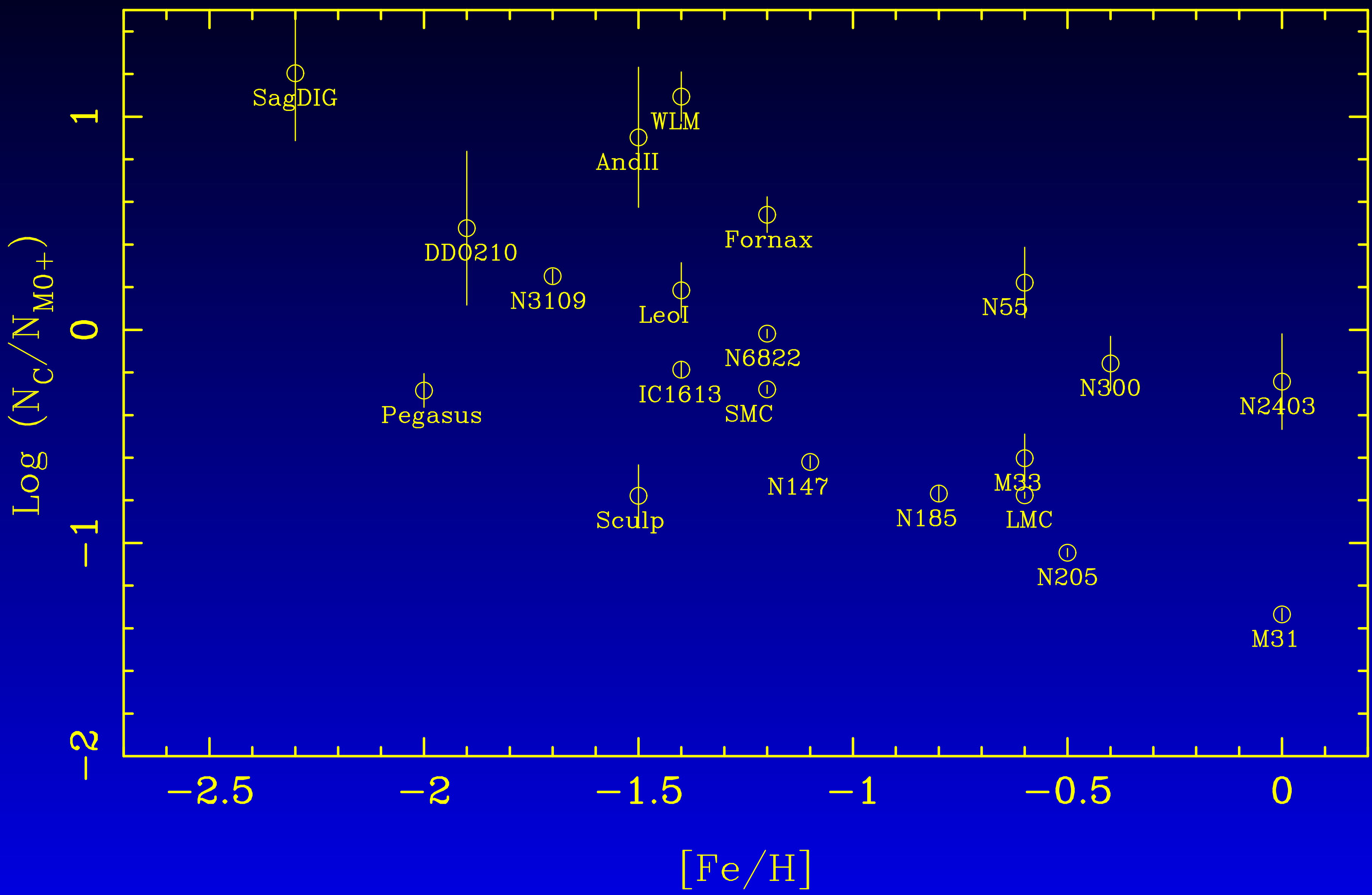


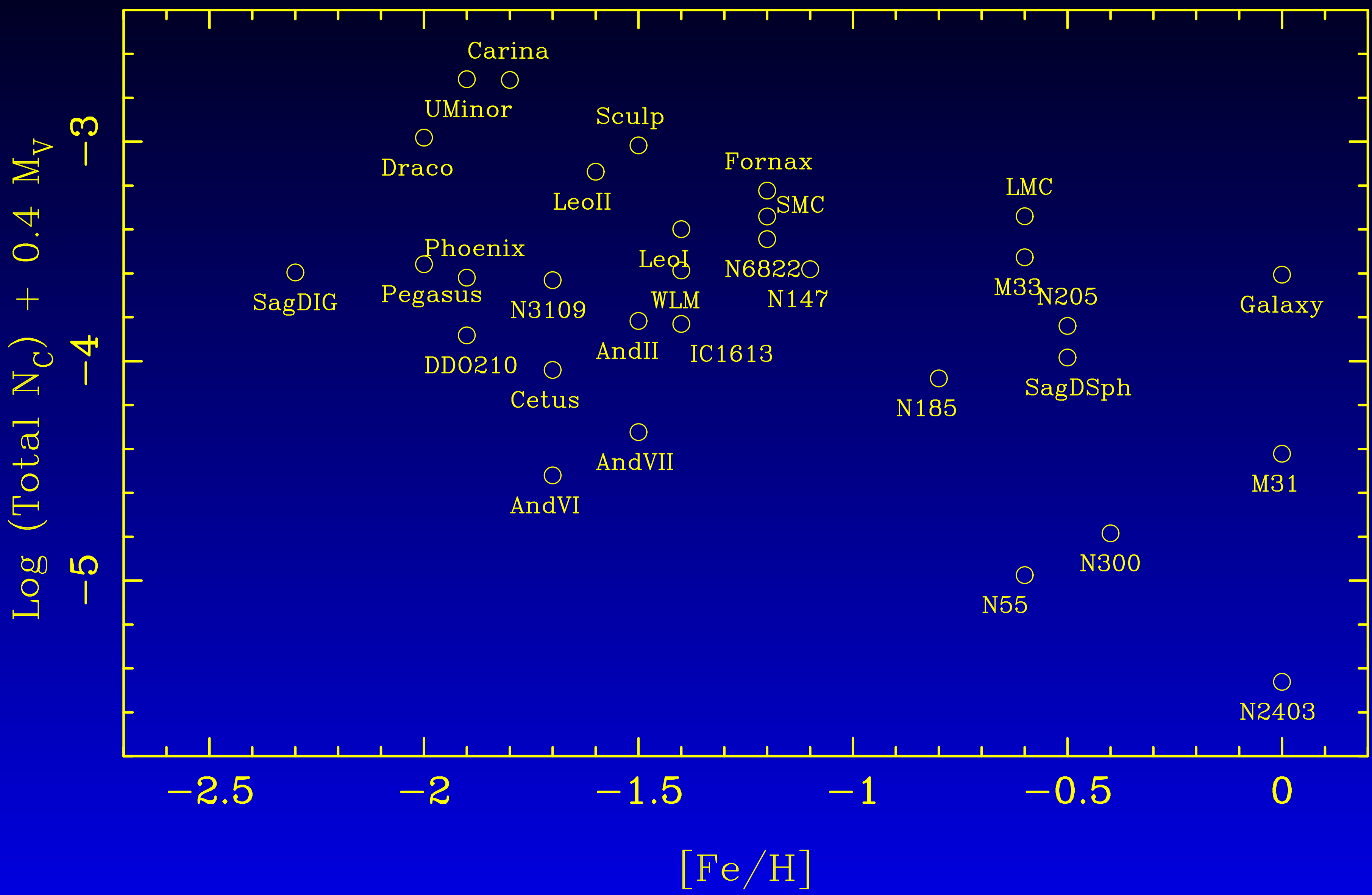
Log (Total Number of C−stars)
0
2
4
−10
−15
−20
M$_V$ (mag)
Galaxy
LMC
M33
M31
SMC
N6822
N3109
N147
N205
IC1613
N300
N2403
Fornax
WLM
N185
SagDSph
N55
LeoI
Pegasus
Carina
SagDIG
UMinor
Sculp
LeoII
AndII
Draco
DDO210
AndVII
Phoenix
Cetus
AndVI



Log (N_C/kpc^2)
0
1
2
−10
−15
−20
M_V (mag)
LMC
SMC
M33
Galaxy
Fornax
Pegasus
N6822
N205
LeoI
Carina
N185
SagDIG
AndII
N3109
M31
LeoII
DDO210
UMinor
Sculp
Draco
AndVII
IC1613
N147
WLM
Phoenix
N55
N300
SagDSph
AndVI
N2403
Cetus


Pegasus
LeoI
Fornax
Sculp
IC1613
SMC
M33
N300
N55
LMC
M31
Log (N_C/N_M5+)
1
0
−1
−2.5
−2
−1.5
−1
−0.5
0
[Fe/H]

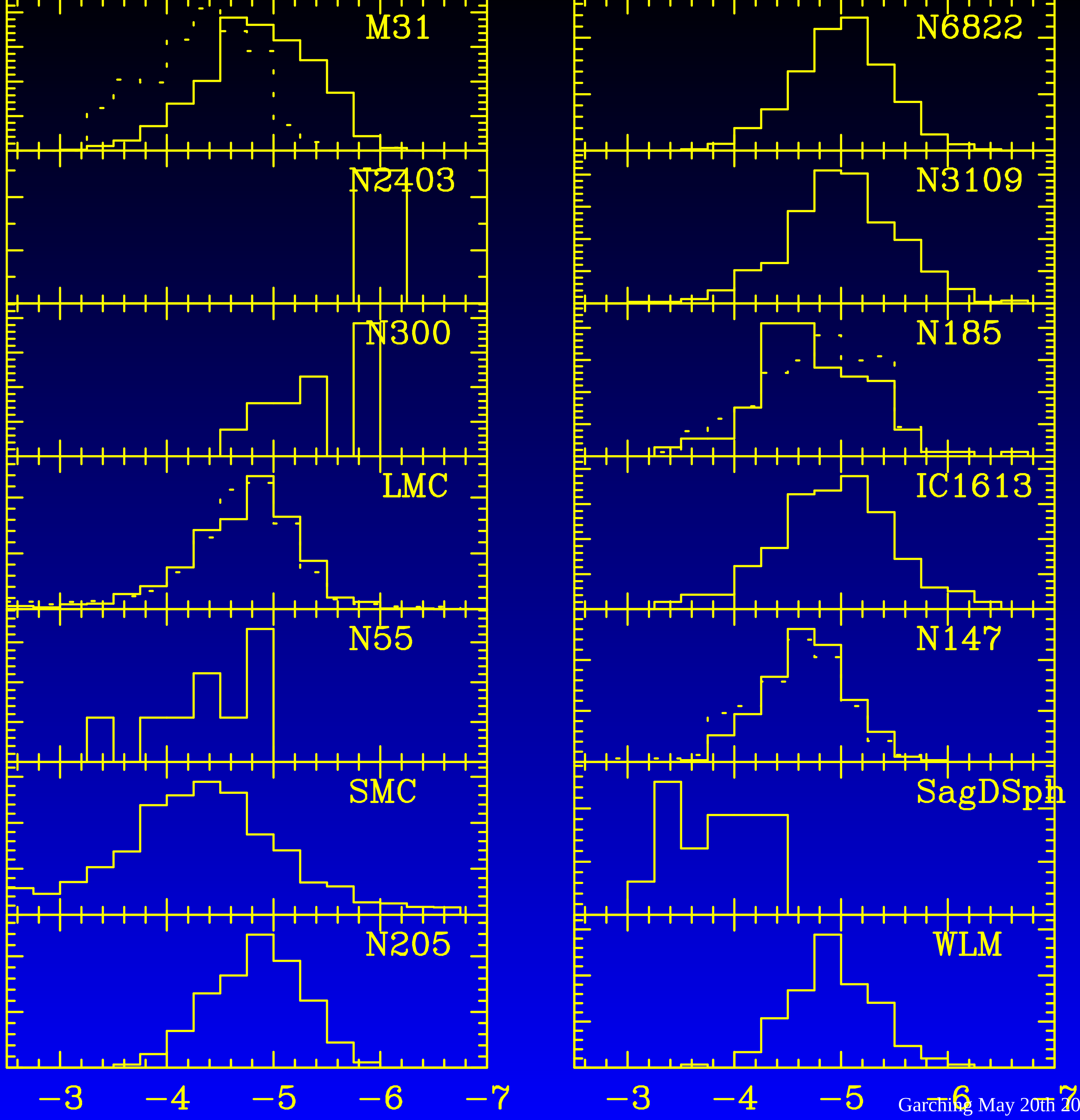

SagDIG
WLM
AndII
Fornax
DDO210
N3109
LeoI
N55
N6822
N300
N2403
Pegasus
IC1613
SMC
N147
Sculp
N185
M33
LMC
N205
M31
1
0
−1
−2
−2.5
−2
−1.5
−1
−0.5
0
Log (N_C/N_{M0+})
[Fe/H]

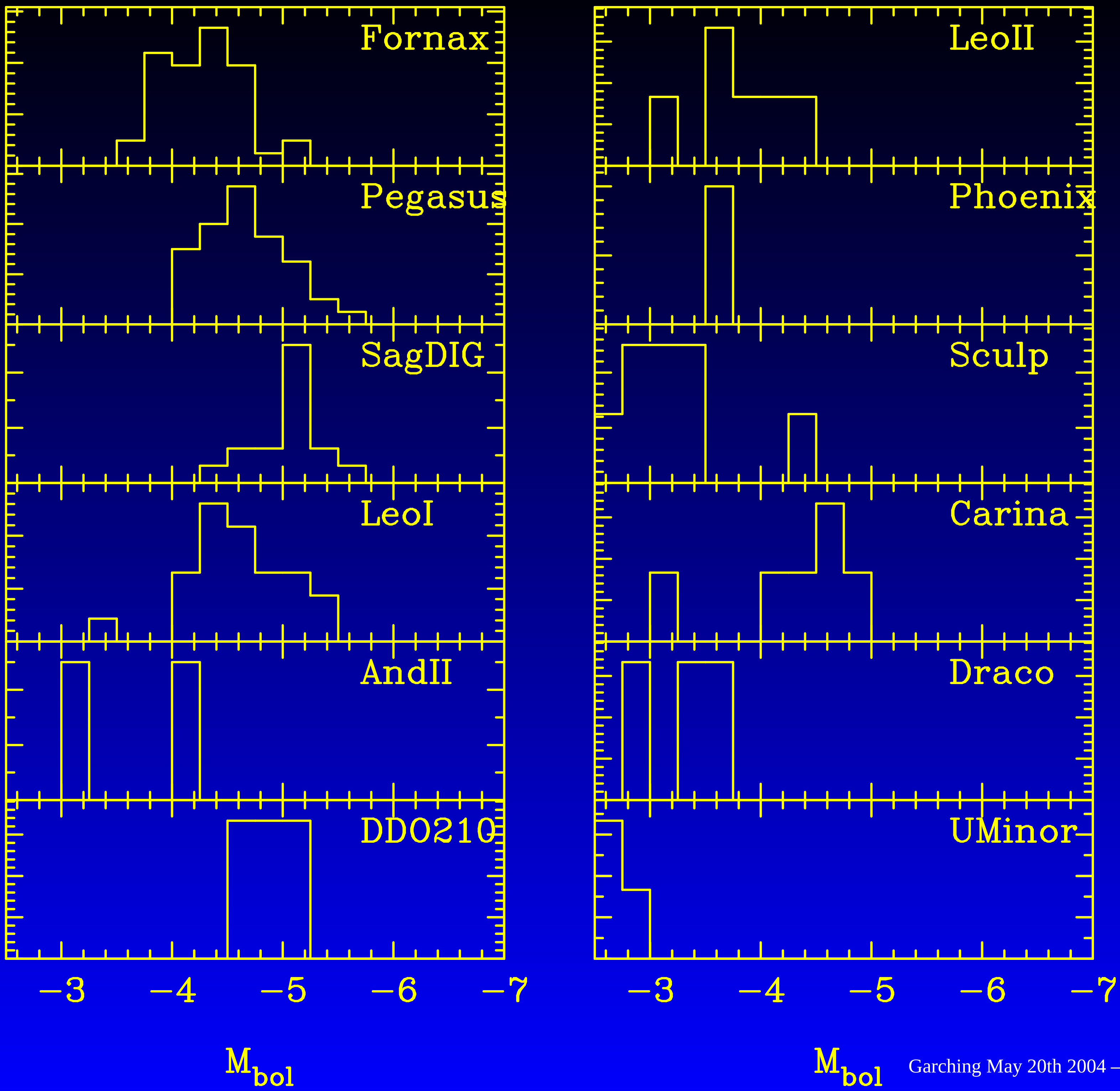

Carina
UMinor
Sculp
Draco
Fornax
LeoII
LMC
SMC
Phoenix
LeoI
N6822
SagDIG
Pegasus
N3109
WLM
N147
M33
N205
Galaxy
AndII
IC1613
DDO210
Cetus
N185
SagDSph
AndVII
M31
AndVI
N300
N55
N2403
Log (Total N_C) + 0.4 M_V
−3
−4
−5
−2.5
−2
−1.5
−1
−0.5
0
[Fe/H]

Name	$M_{\rm bol}^{\rm max}$ (mag)	$M_{\rm bol}^{\rm min}$ (mag)	$M_{\rm bol}^{\rm mean}$ (mag)	spread (mag)	$N_{\rm all}$	$N_{\rm M_{bol}>-3.5}$
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

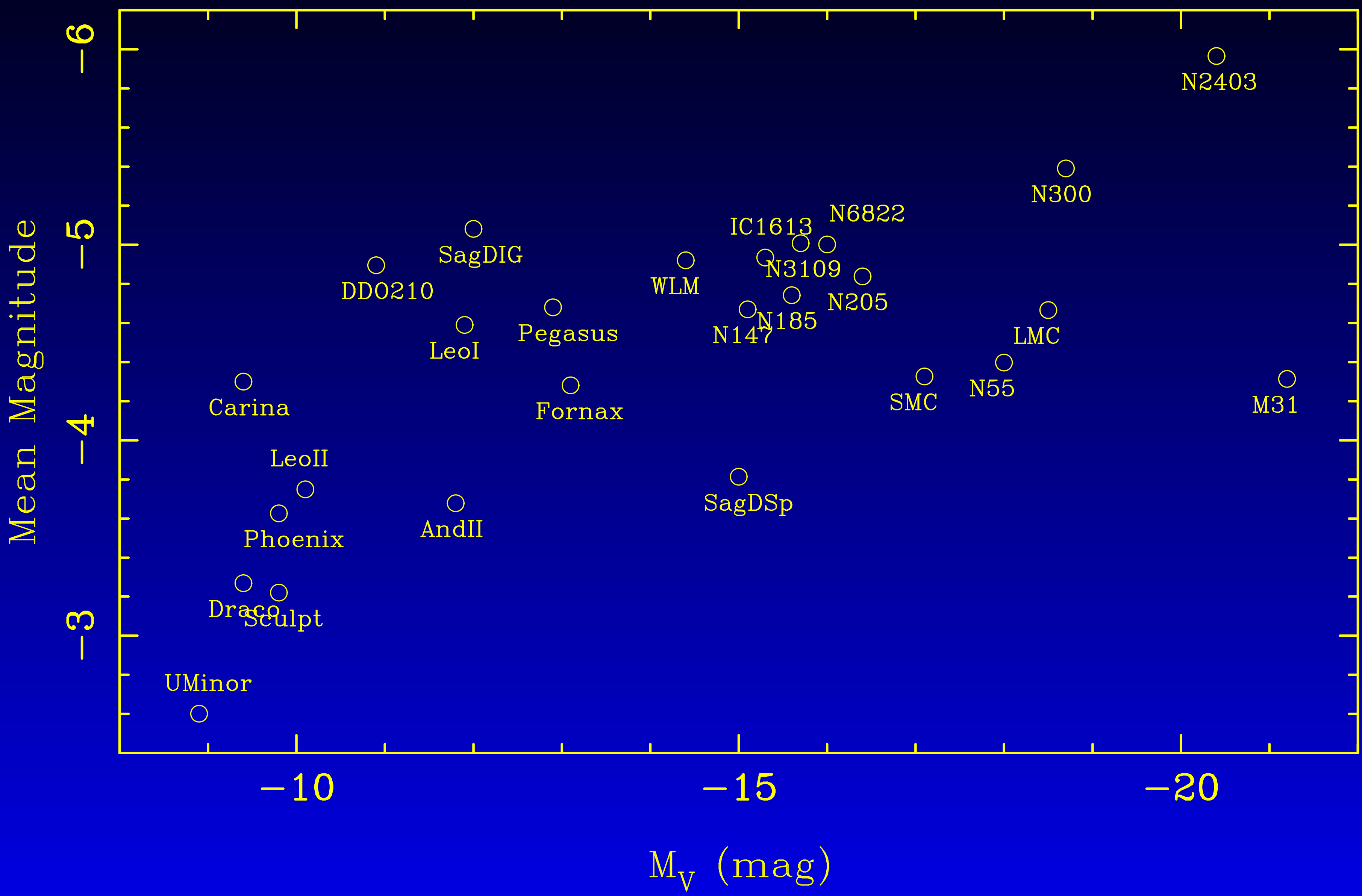
Name	$M_{\rm bol}^{\rm max}$ (mag)	$M_{\rm bol}^{\rm min}$ (mag)	$M_{\rm bol}^{\rm mean}$ (mag)	spread (mag)	$N_{\rm all}$	$N_{\rm M_{bol}>-3.5}$
N147	-5.94	-3.53	-4.67	0.40	288	0
SagDSph	-4.37	-3.11	-3.81	0.40	16	5
WLM	-6.11	-3.73	-4.92	0.40	149	0
Fornax	-5.22	-3.64	-4.28	0.36	41	0
Pegasus	-5.59	-4.05	-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	$M_{\rm bol}^{\rm max}$ (mag)	$M_{\rm bol}^{\rm min}$ (mag)	$M_{\rm bol}^{\rm mean}$ (mag)	spread (mag)	$N_{\rm all}$	$N_{\rm M_{bol}>-3.5}$
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

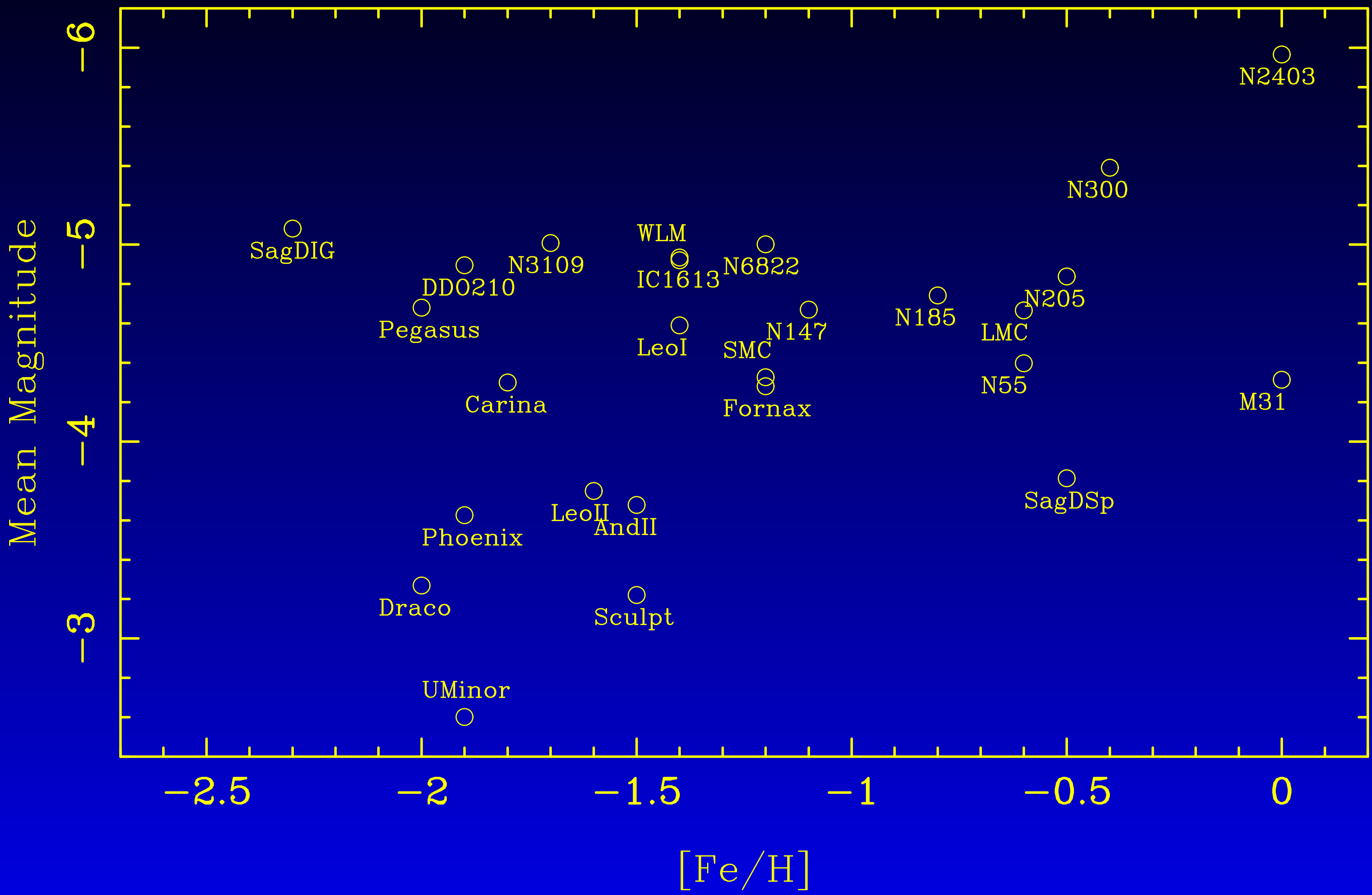

M31
N6822
N2403
N3109
N300
N185
LMC
IC1613
N55
N147
SMC
SagDSph
N205
WLM
−3
−4
−5
−6
−7
−3
−4
−5
−6
−7

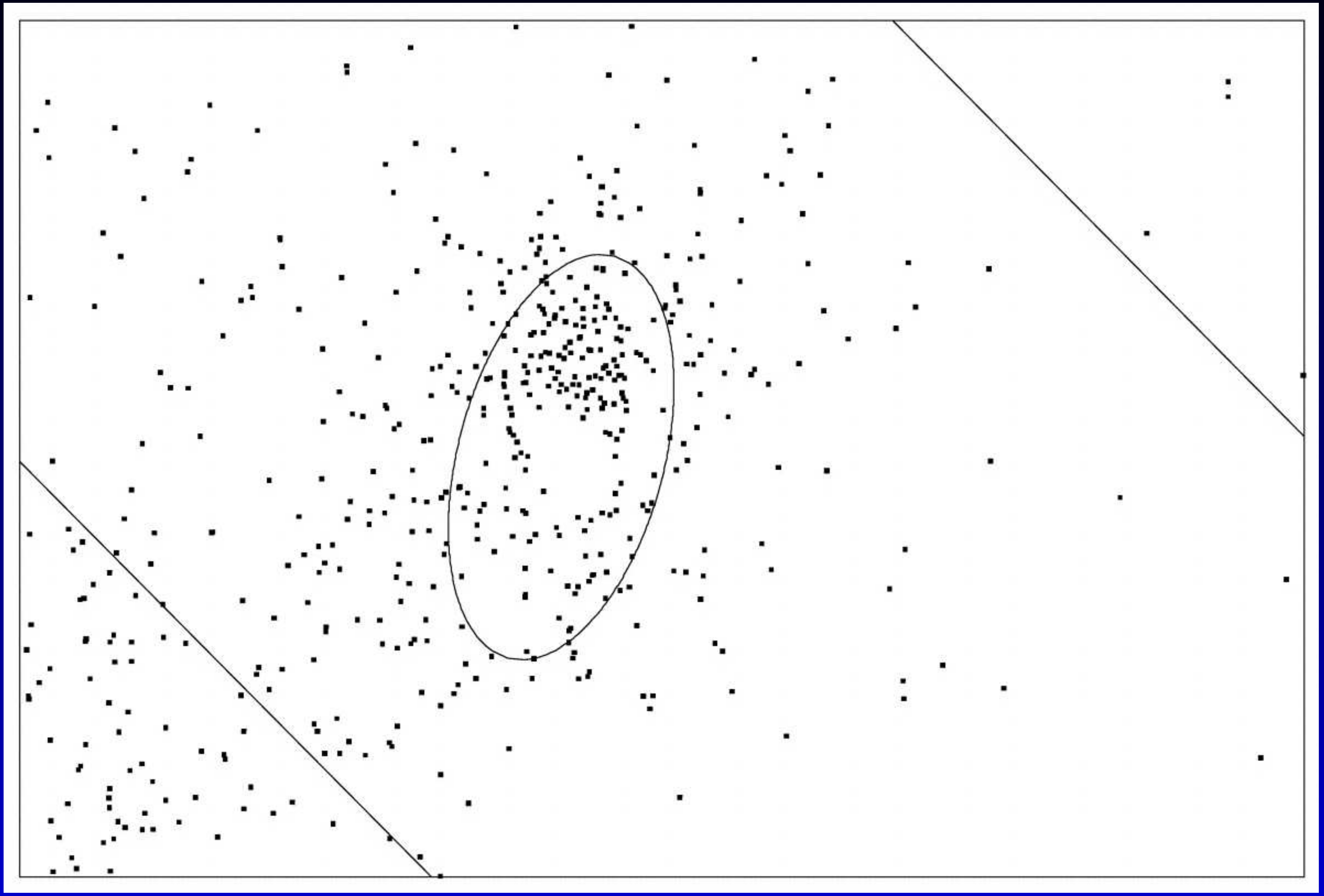


Fornax
Pegasus
SagDIG
LeoI
AndII
DDO210
LeoII
Phoenix
Sculp
Carina
Draco
UMinor
−3
−4
−5
−6
−7
M_bol

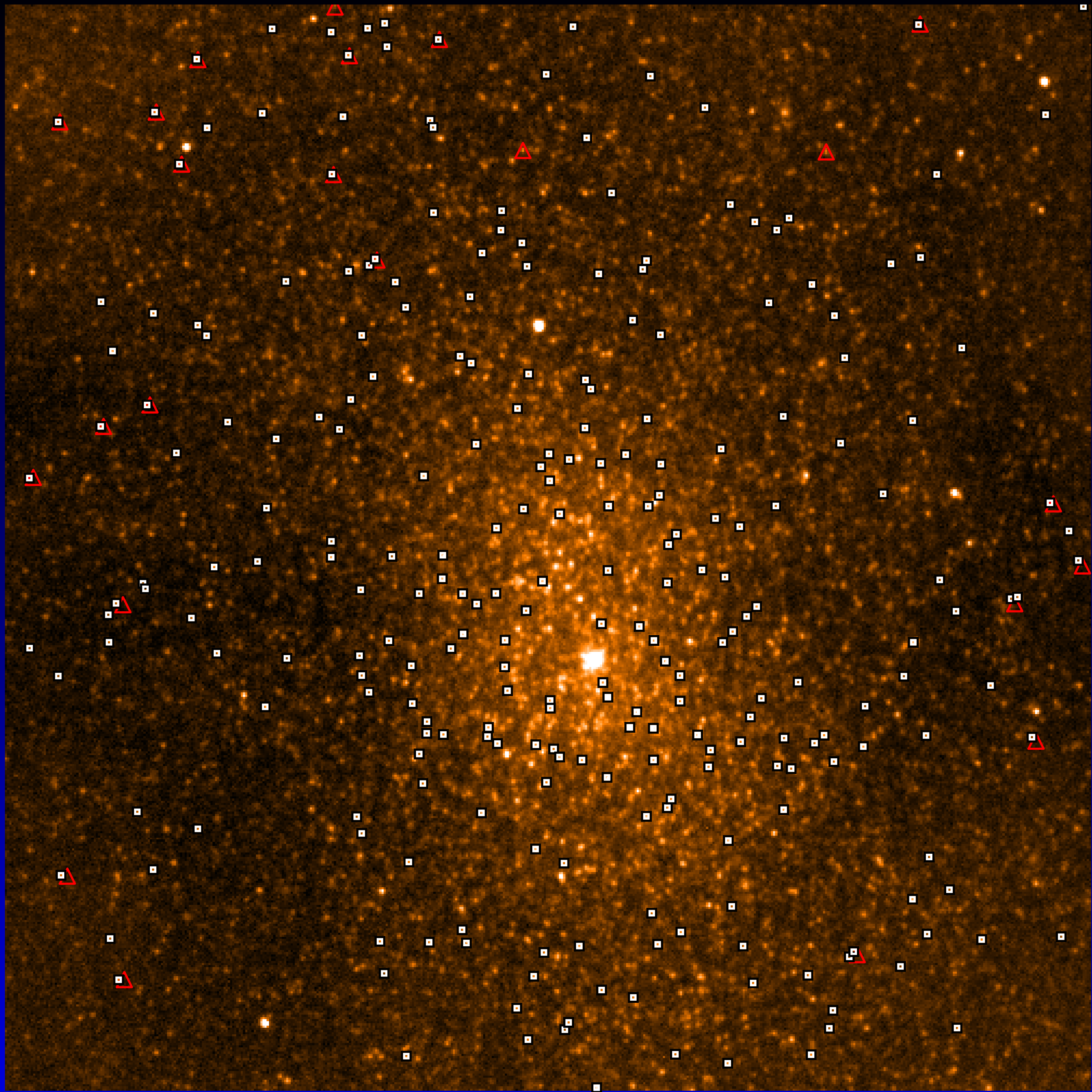


Mean Magnitude
−6
−5
−4
−3
−10
−15
−20
M_V (mag)
N2403
N300
N6822
IC1613
SagDIG
N3109
WLM
DDO210
N205
Pegasus
N185
LeoI
N147
LMC
N55
SMC
M31
Carina
Fornax
LeoII
SagDSp
AndII
Phoenix
Draco
Sculpt
UMinor

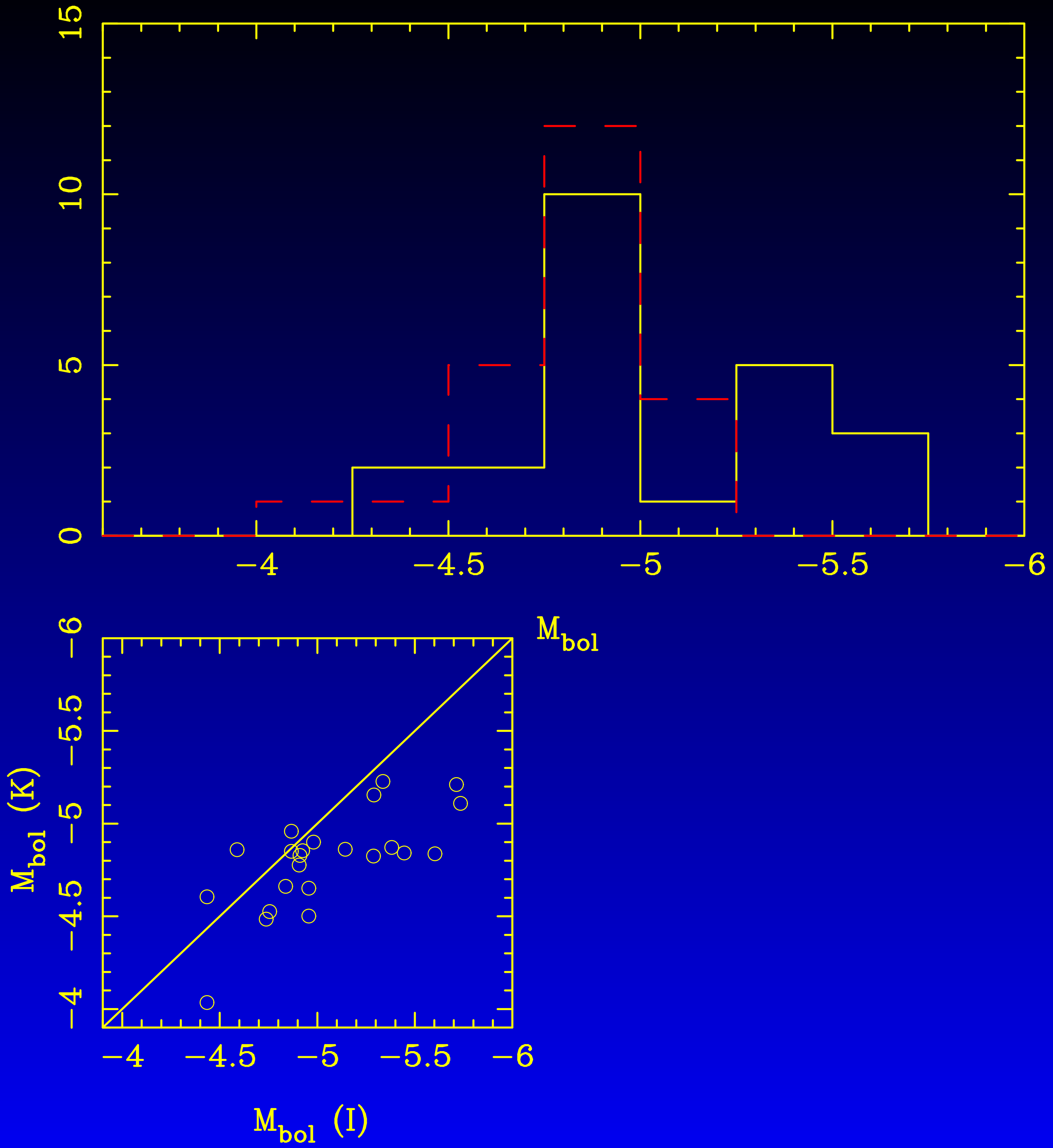

Mean Magnitude
[Fe/H]
−6
−5
−4
−3
−2.5
−2
−1.5
−1
−0.5
0
N2403
N300
SagDIG
N3109
WLM
IC1613
N6822
DDO210
Pegasus
N185
N205
LMC
N147
SMC
LeoI
N55
M31
Carina
Fornax
SagDSp
LeoII
AndII
Phoenix
Draco
Sculpt
UMinor



Demers et al. (2003) for NGC 205



NGC 205: $4'$ x $4'$ K-image; known C-stars ($\triangle$)
$(J-K)_0 > 1.5$ $K_0 < 17.2$ ($\square$)



15
10
5
0
−4
−4.5
−5
−5.5
−6
M_{bol}
−6
−5.5
−5
−4.5
−4
M_{bol} (K)
−4
−4.5
−5
−5.5
−6
M_{bol} (I)

Future: narrow band imaging

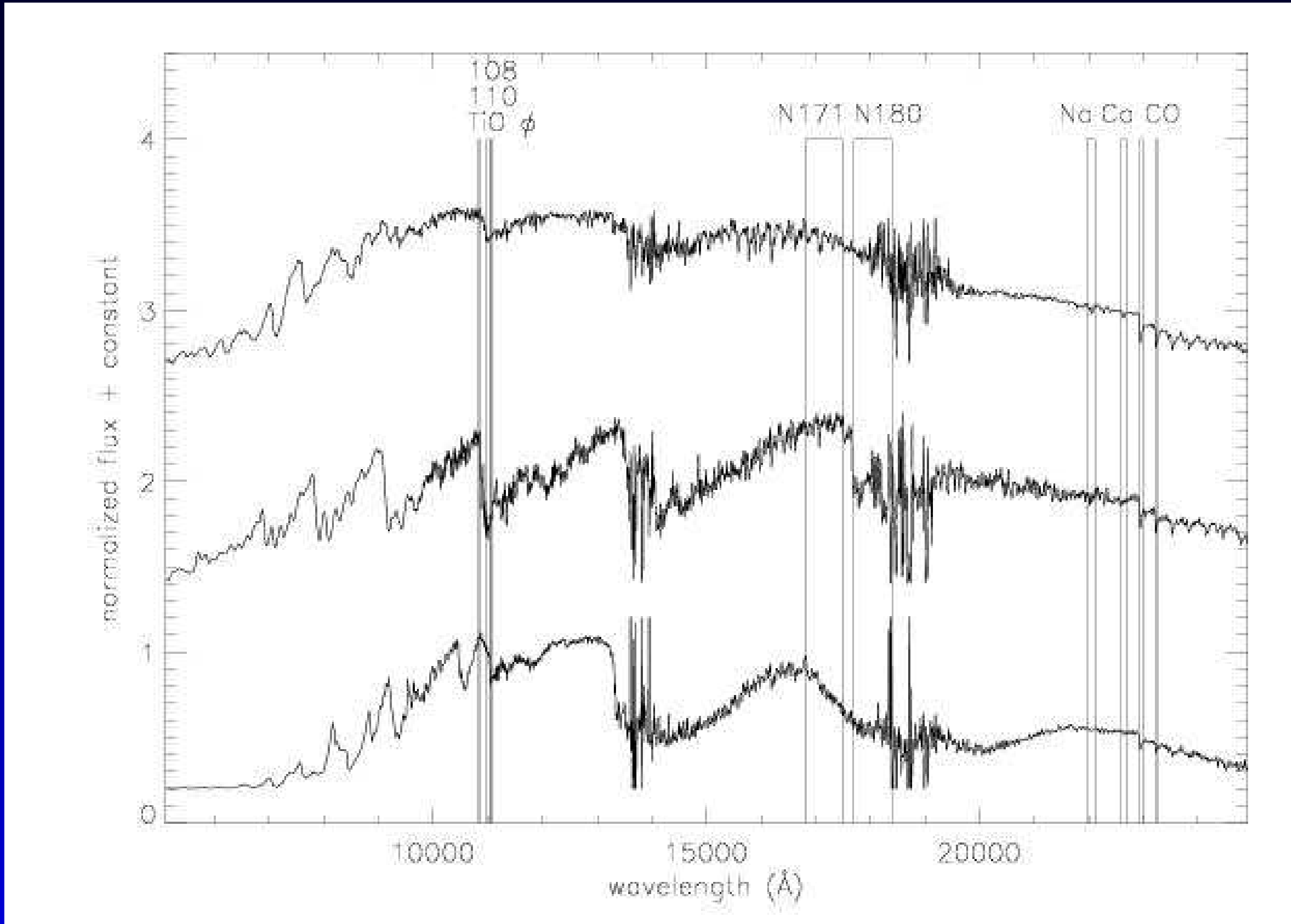
- (Groenewegen et al.:) Carina, Sculptor, Phoenix
- (Demers & Battinelli:) IC 10
- (Vienna group:)
  And II (submitted), M32 (reduced), Leo I, Leo II, Draco, Ursa Minor (acquired)

  4.1m SOAR telescope, 5.5′ FOV

Future: IR

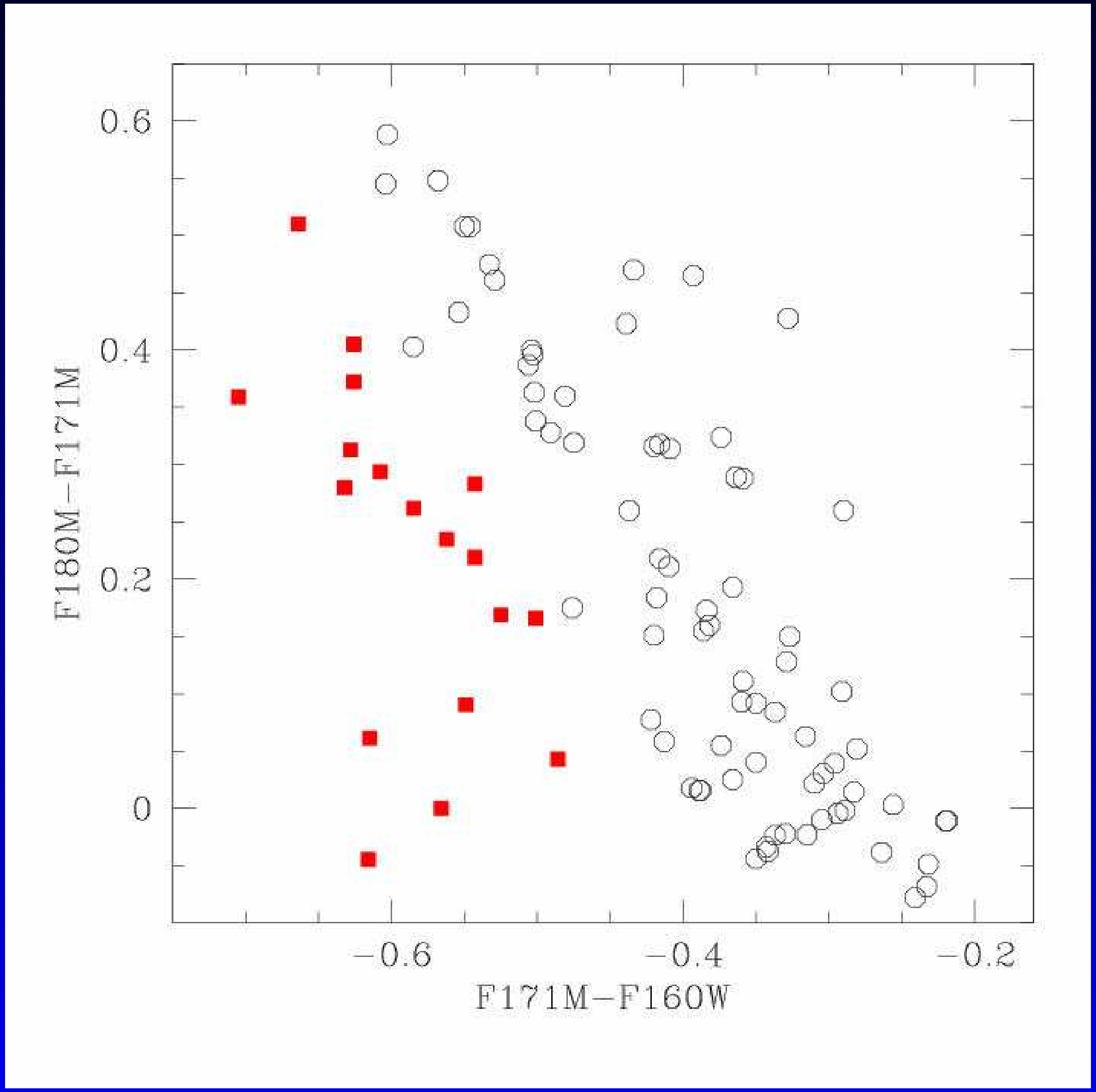
- Enrico Held/ SOFI: Fornax, Leo I, Leo II, Carina, Sculptor, Phoenix, Sextans
- Menzies et al. (SAAO+Japan)/ IRSF/ SIRIUS: Leo I, Fornax, (+all smaller LG)
- Cioni, Habing et al./ WHT/ INGRID: Leo A, Leo I, Leo II, Sex B, NGC 6822, Draco, NGC 147, NGC 185
- Rome+Montreal/ CTIO 1.5m/ CPAPIR: monitor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

Narrow-band in the NIR



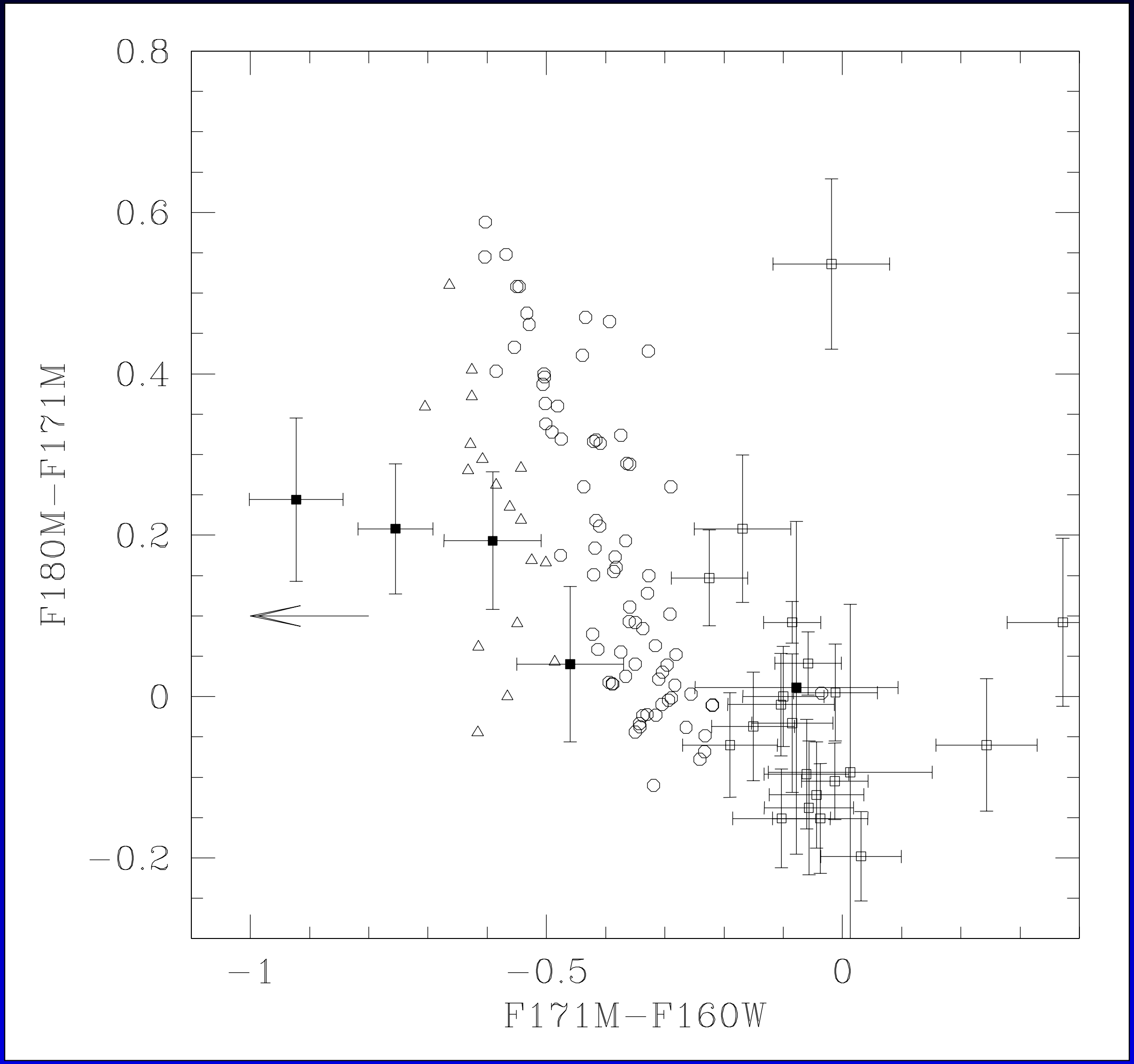
NICMOS filters; M-SG, C, M

Narrow-band in the NIR



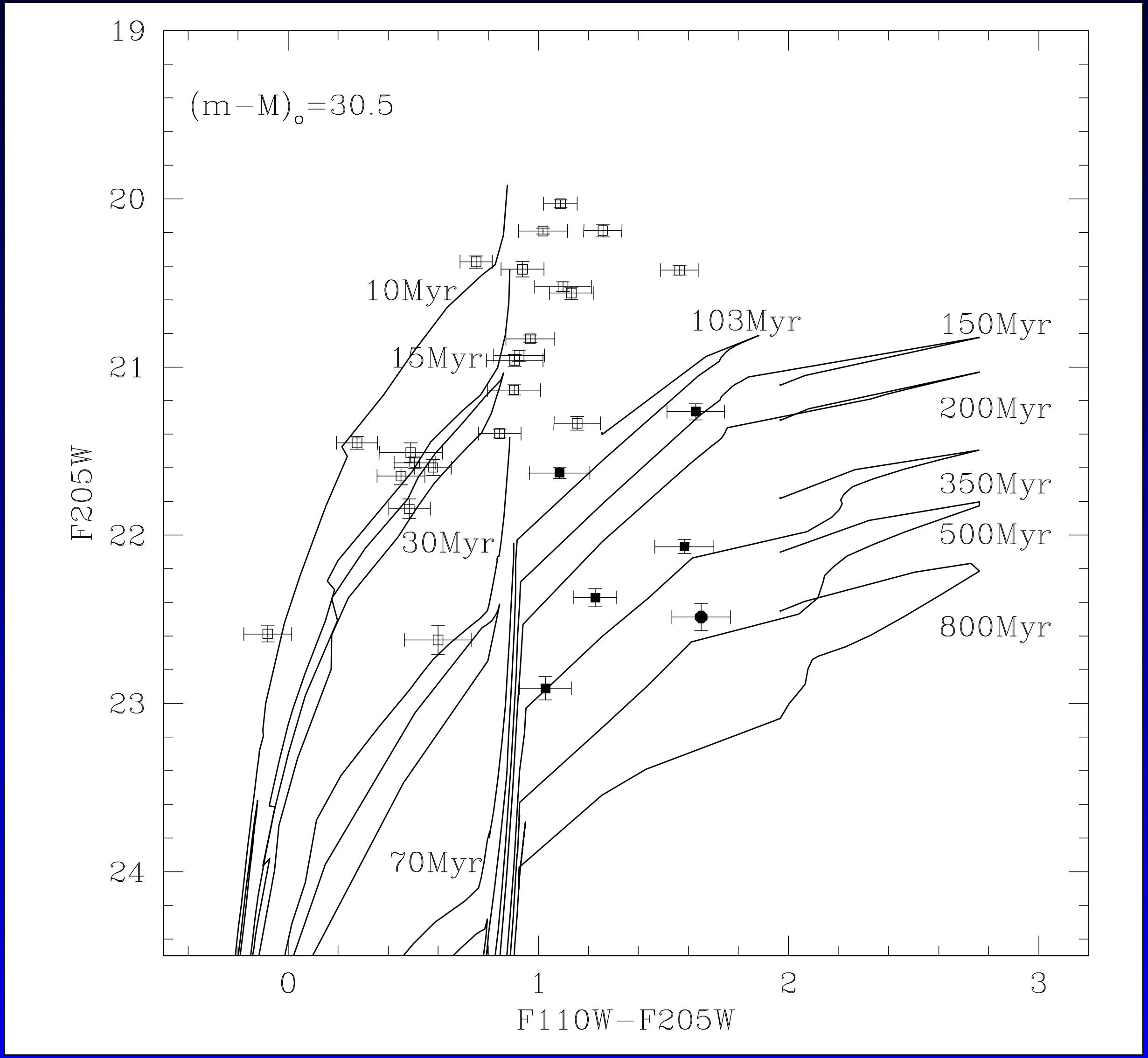
local sample: M (white circles), C (red squares)

Narrow-band in the NIR



I Zw 18

Narrow-band in the NIR



I Zw 18

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 $K = 22.8$ $M_{\rm bol} = -5.0$
$J - K$ = 1.6 $K = 21.4$ $M_{\rm bol} = -6.1$

Theory

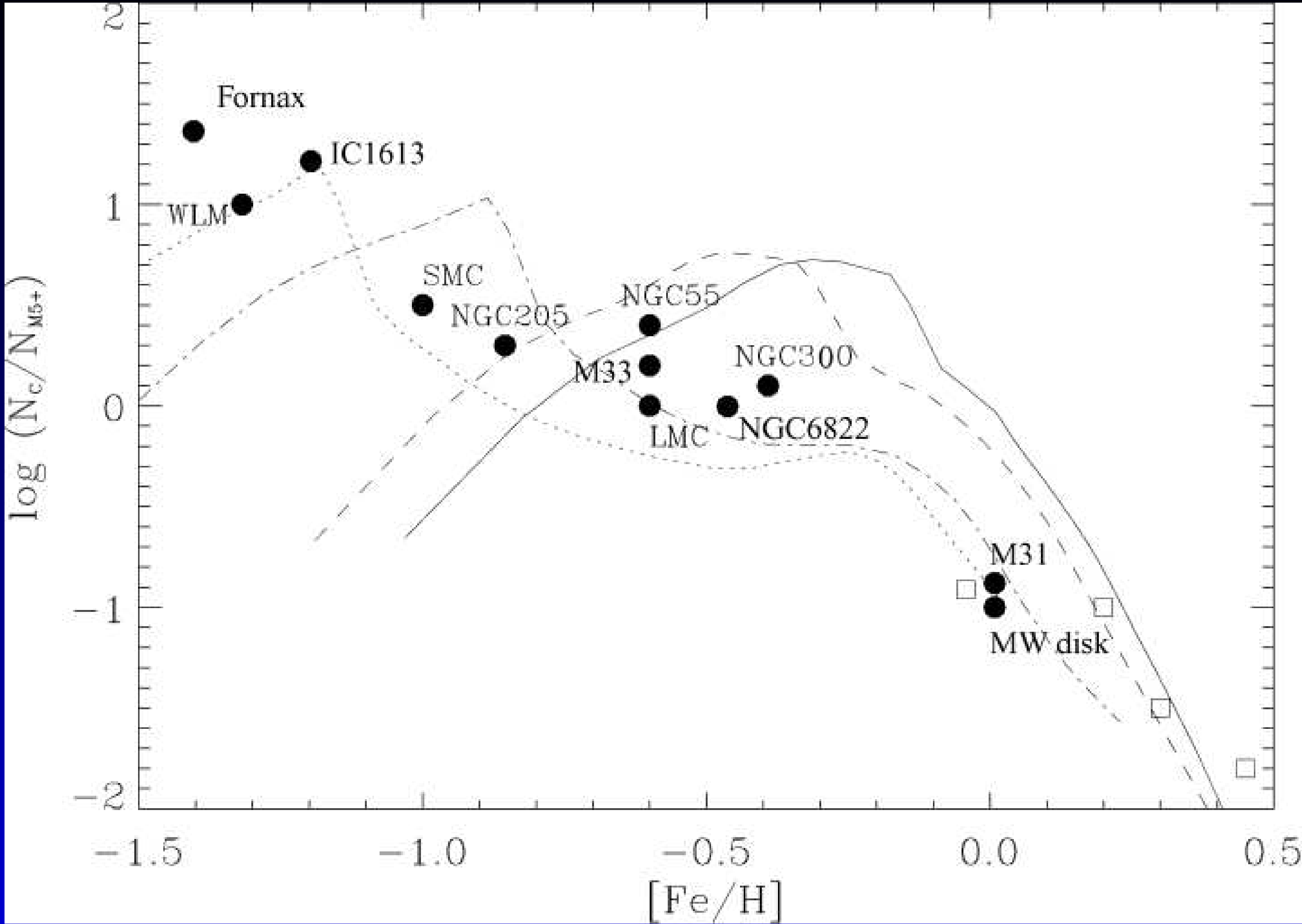
- Mouhcine & Lançon (2003)

  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