AGB stars in extragalactic systems

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Introduction

- Known distance and foreground reddening
- Different AMR, SFR
- $\dot{M}$ = F (Z, M)
- C/M ratio: globally, or spatially resolved
- Study structure and kinematics of galaxies

Overview of this talk

- How to find AGB stars ?

  Infra-red colours $\Longleftrightarrow$ cool, dust

  Variability $\Longleftrightarrow$ large amplitude, long period

  Narrow-band filters $\Longleftrightarrow$ spectral characteristics

- Recent work on individual objects

  Spitzer IRS results on C-stars in the MCs

  NIR spectroscopy of AGB candidates in Fornax and Sculptor dSph

  Abundance studies

Overview of this talk

- Inventory / Status report

  Update of:
  -Groenewegen (1999, IAU Symp 191)
  -Azzopardi (1999, Ap&SS 265, 291)
  -Groenewegen (Ringberg, astro-ph/0208449)
  -Groenewegen (2004, “Planetary Nebulae beyond the Milky Way”)

How to identify late-type stars ?

- (Infra-red) broadband photometry

  Disadvantage:

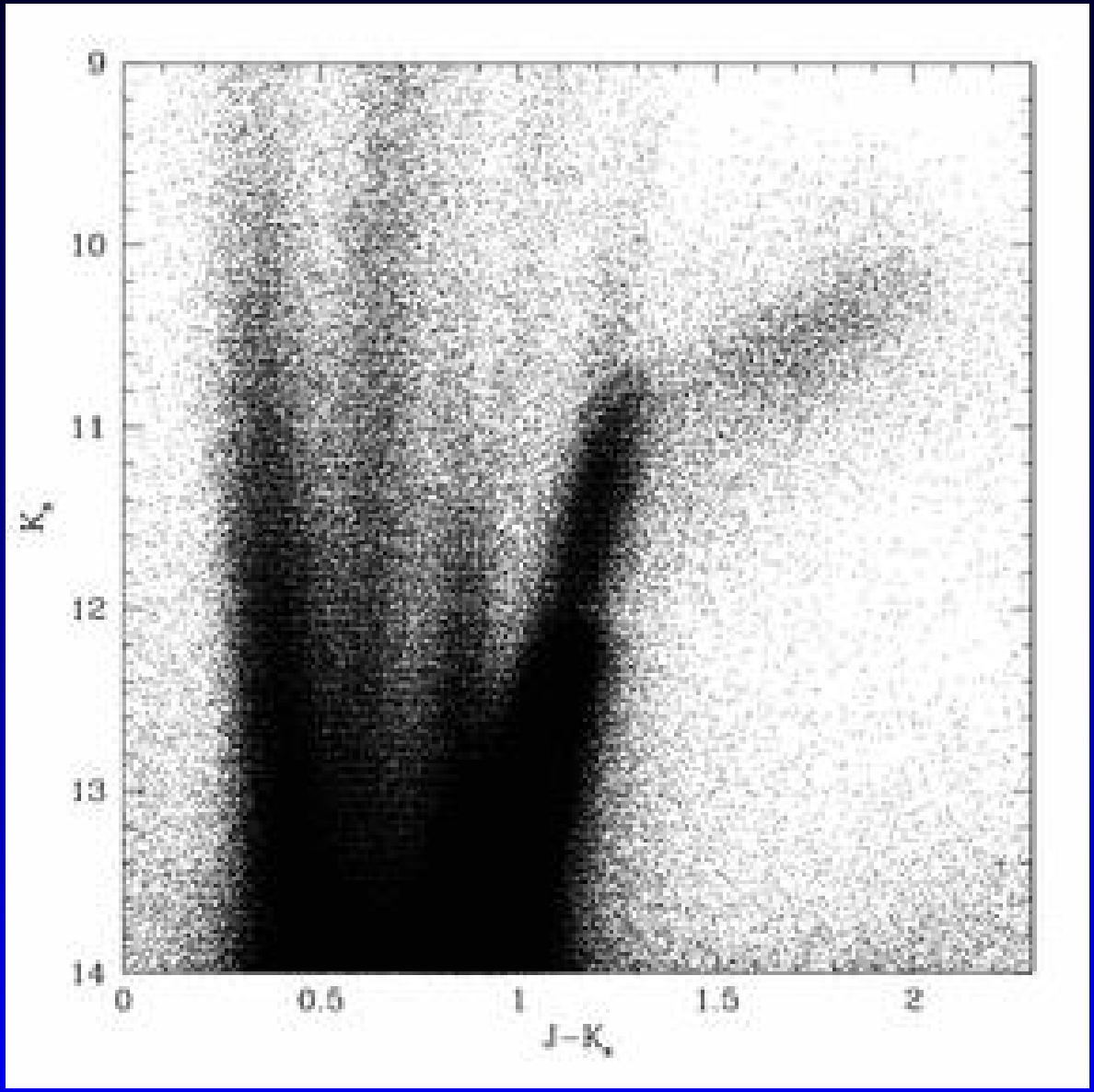
  Candidates only,
  $(J - K)$ colour is often used to discriminate M/C

  [see later]

  Advantage:

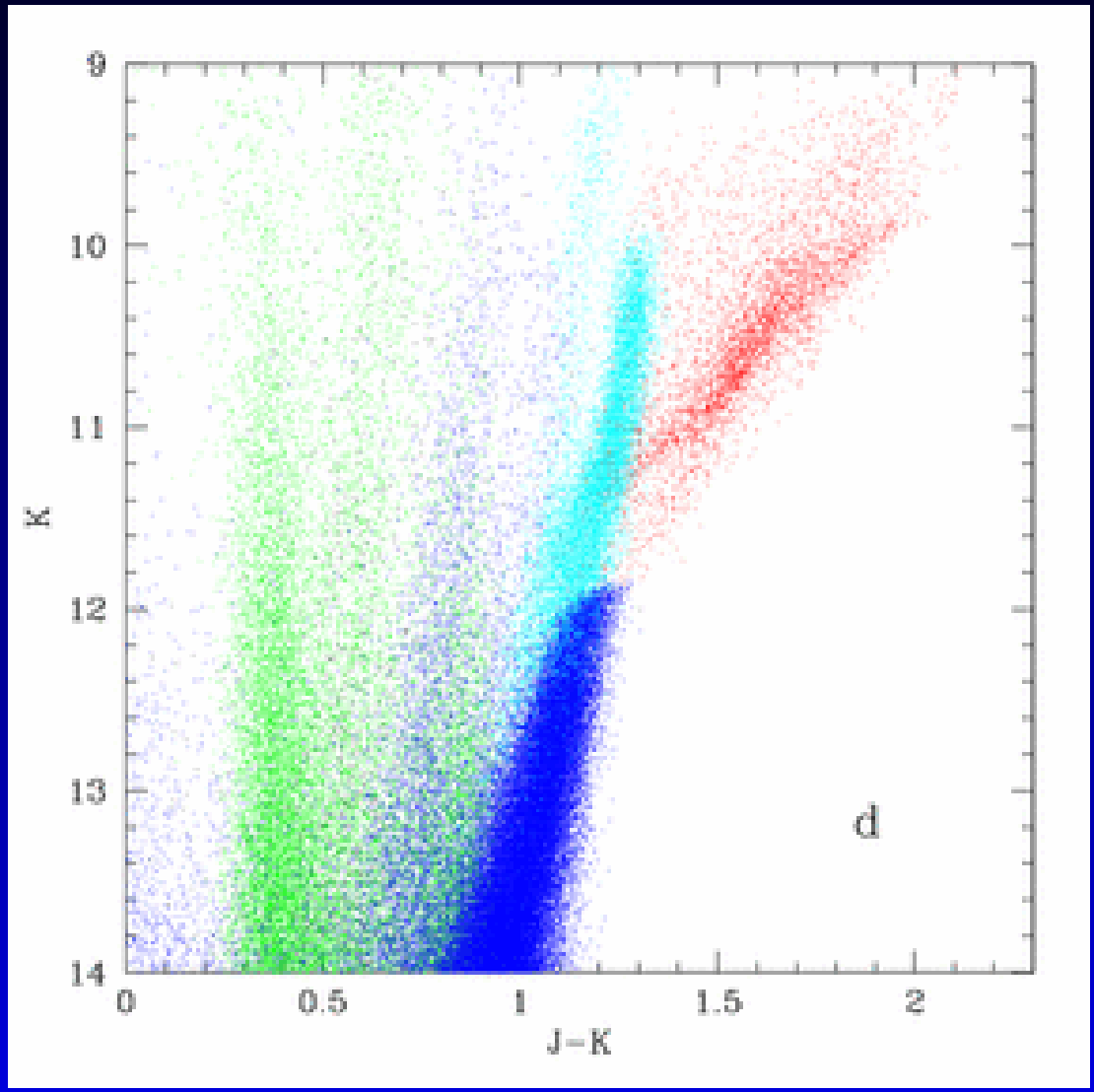
  Very red colours trace a different population

2MASS



LMC 2MASS Marigo et al. 2003

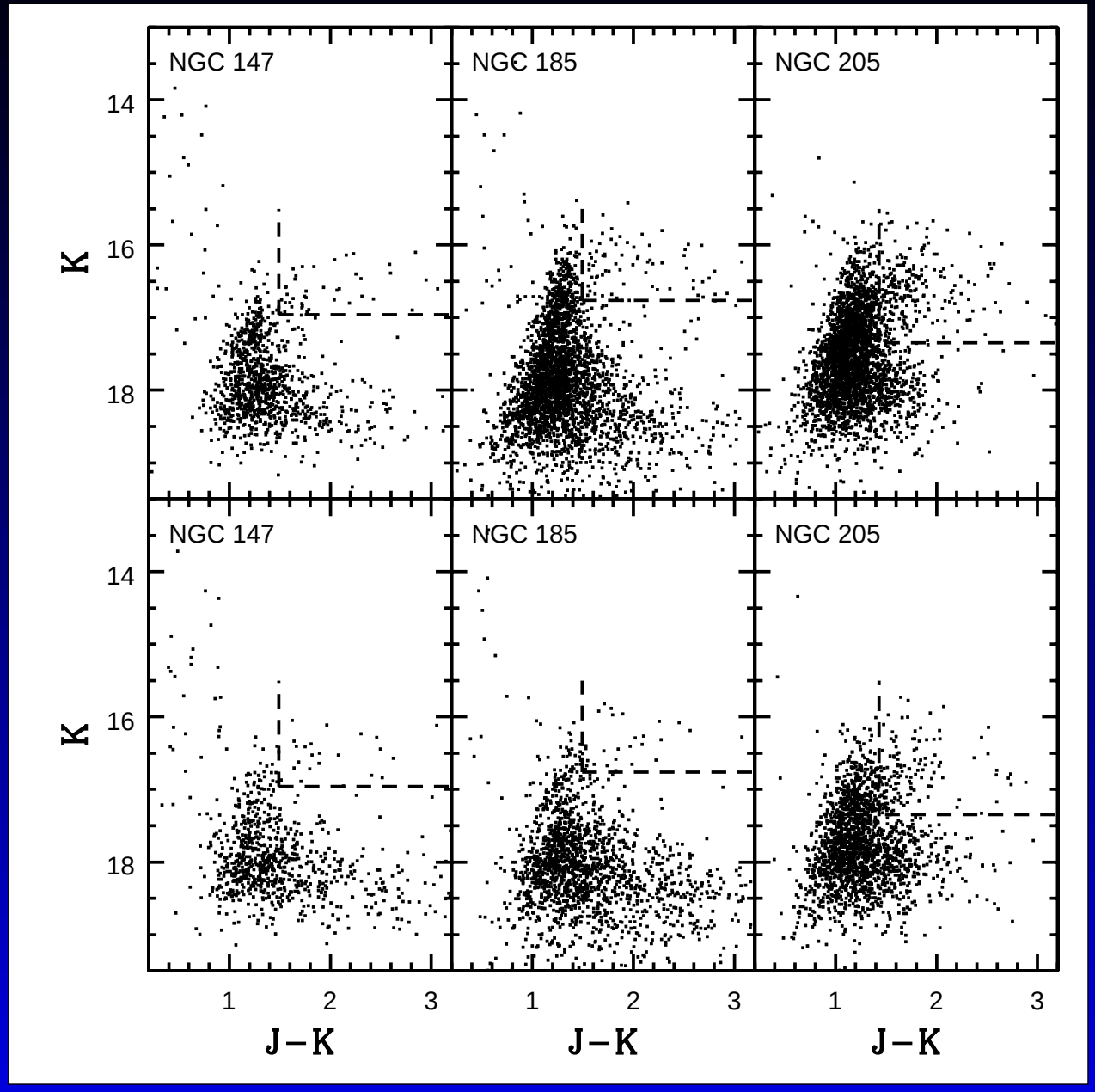
2MASS



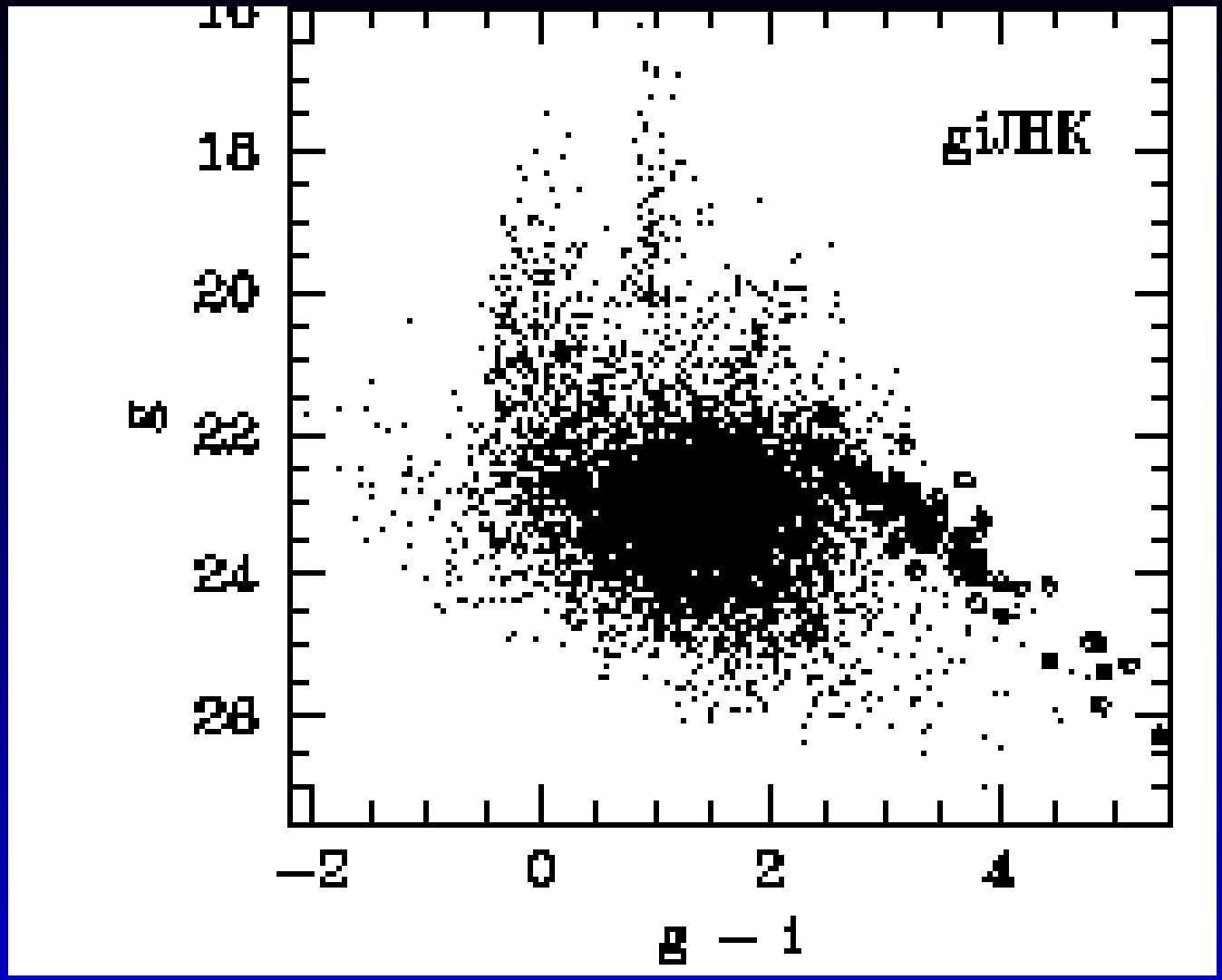
LMC simulations Marigo et al. 2003
Role of molecular opacities.

NIR work

- Demers et al. (2002): C-stars in MCs and Fornax
- Cioni et al. (2003): spatial C/M ratio over MCs
- Tsalmantza et al. (2006): bright AGB stars in MCs, M31, M33
- Cioni et al. (2005): IJK, 40′ x30′ on Draco
- Cioni et al. (2005): IJK, 20′ x20′ on NGC 6822
- Kang et al. (2006): $giJHK$, 6.3′ x 3.6′ on NGC 6822
- NGC 147, 185, 205: Davidge (2005), Kang et al. (2005), Sohn et al. (2006)
- Rejkuba et al. (2006): dwarf ellipticals in Cen A

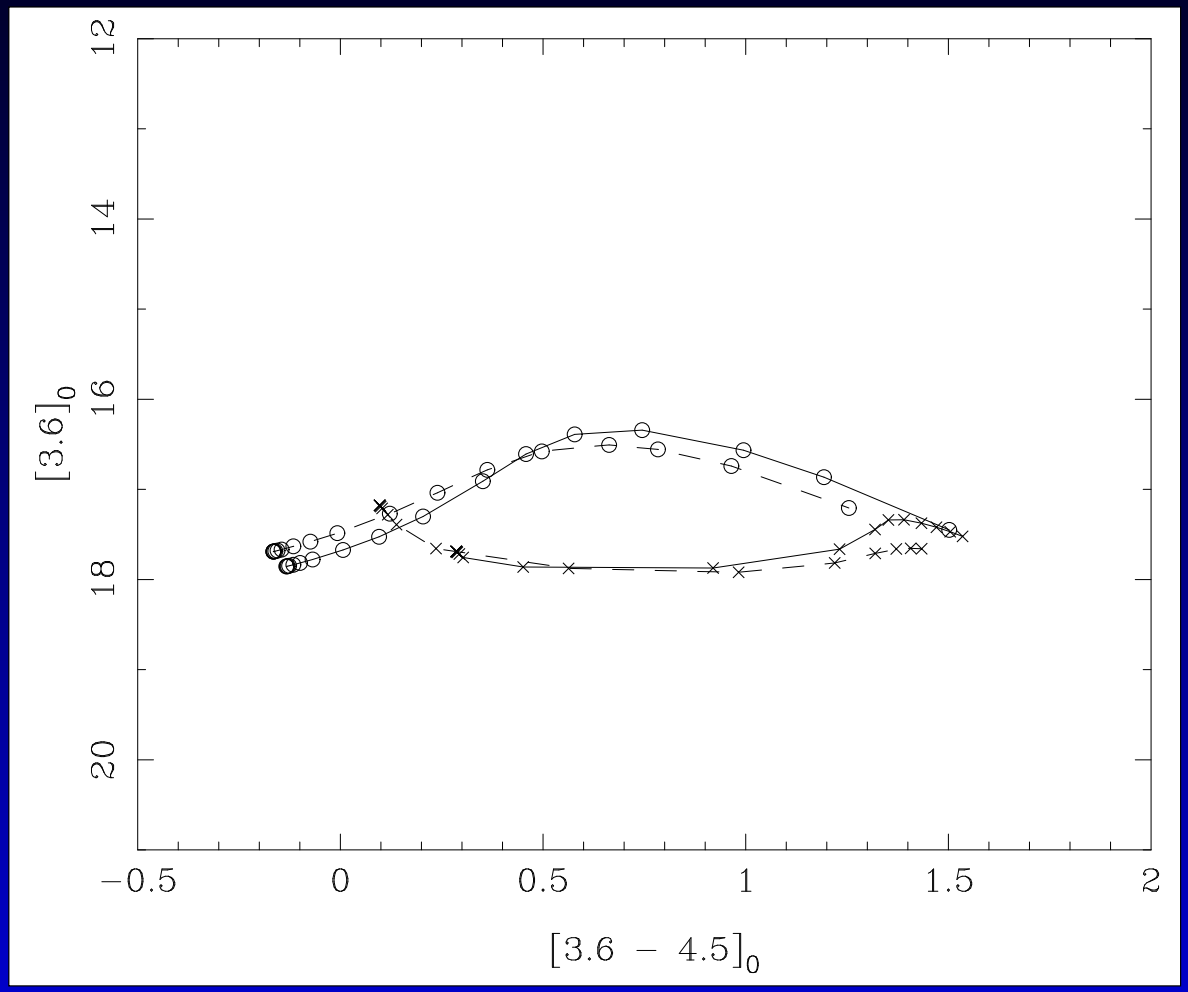


Davidge (2005)

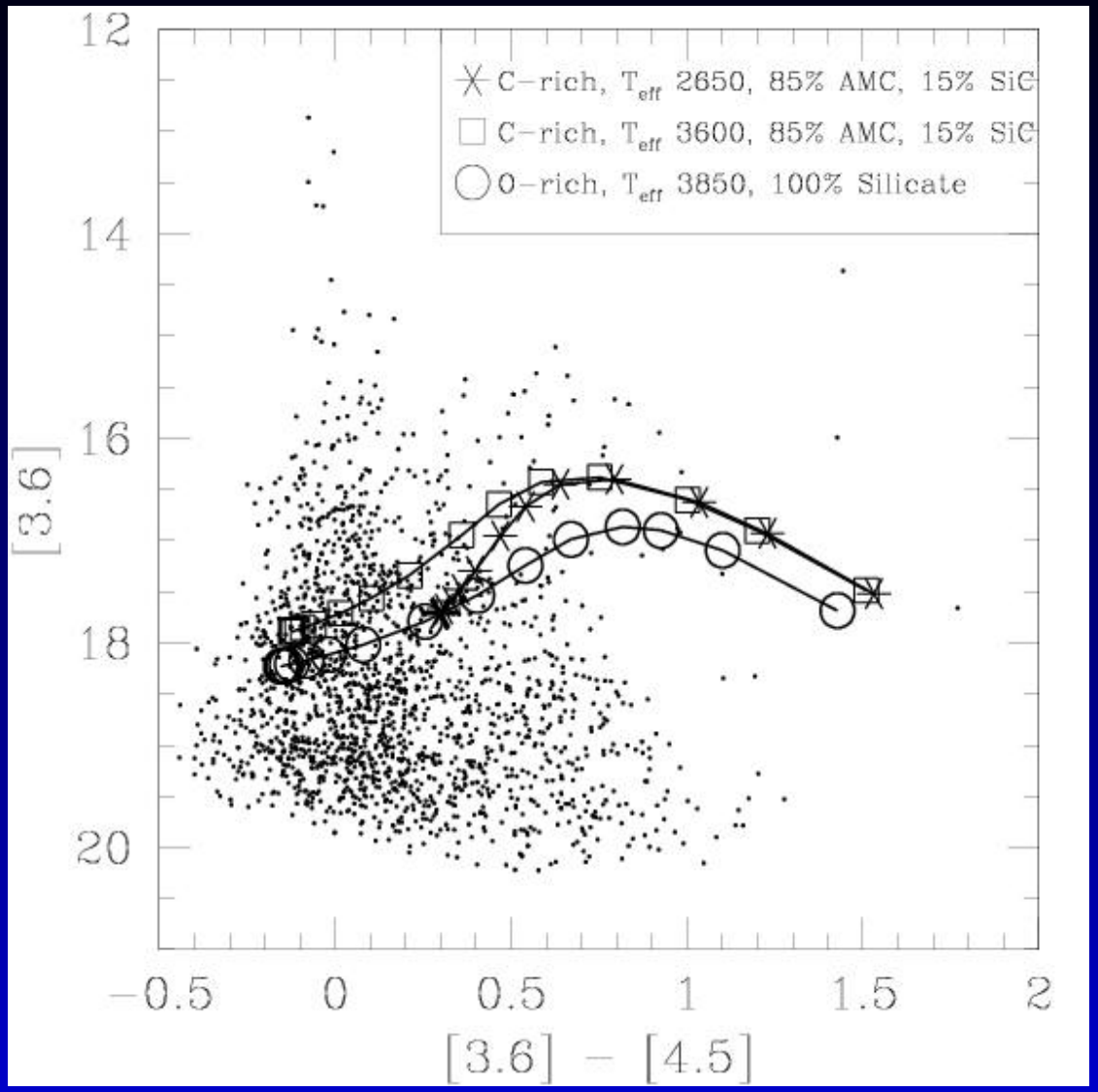


Kang et al. (2006) - NGC 6822

Spitzer IRAC



C- and O-rich AGB and post-AGB colours for 3000 $L_\odot$ at 932 kpc (WLM). (Groenewegen 2006)


C−rich, T_eff 2650, 85% AMC, 15% SiC
C−rich, T_eff 3600, 85% AMC, 15% SiC
O−rich, T_eff 3850, 100% Silicate
12
14
16
18
20
[3.6]
−0.5
0
0.5
1
1.5
2
[3.6] − [4.5]

How to identify late-type stars ?

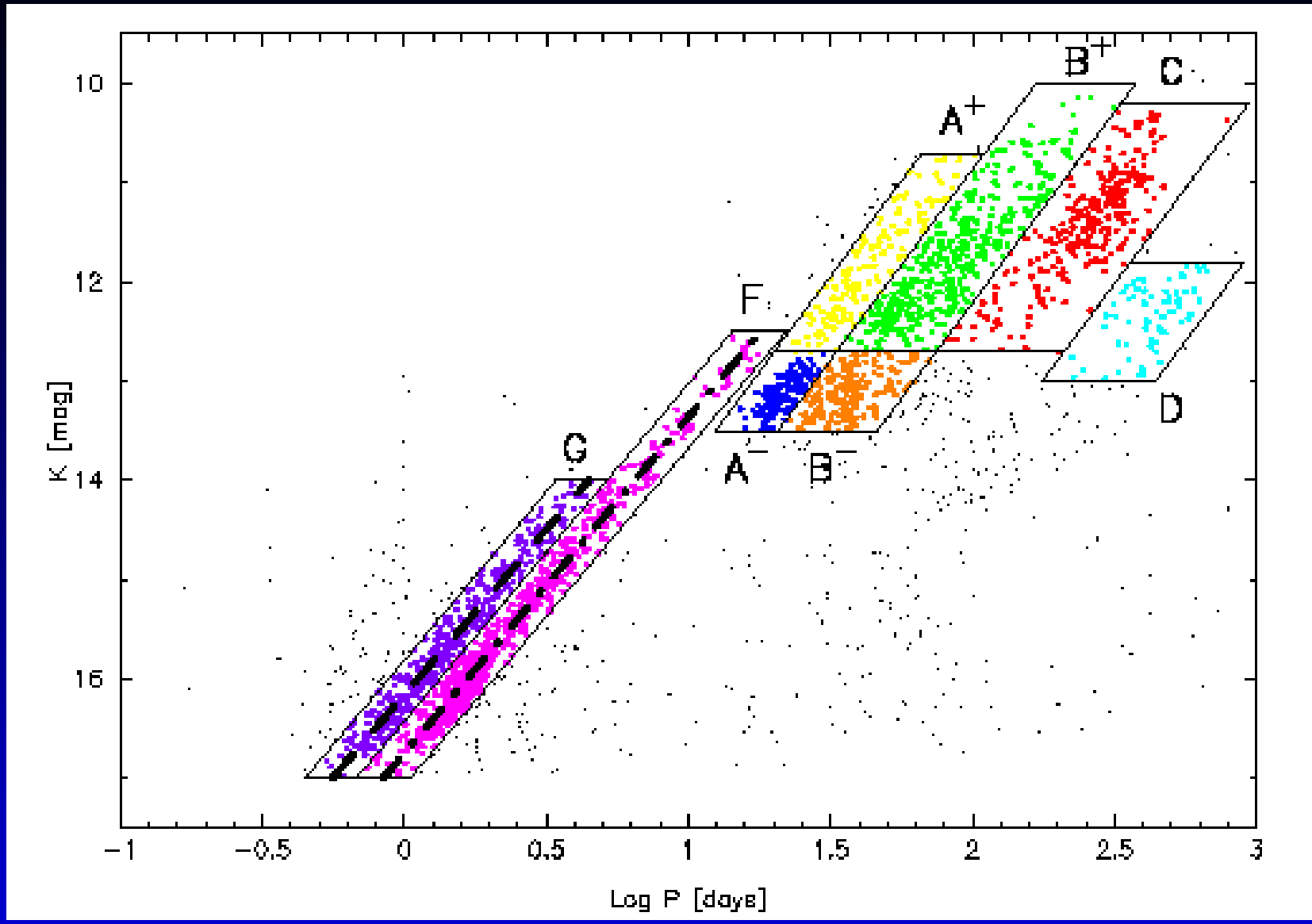
- Variability

  Disadvantage:

  No M/S/C discrimination
  Observing time demanding

  Advantage:

  PL-relation
  Distance estimates



Ita et al. (2004)

Variability

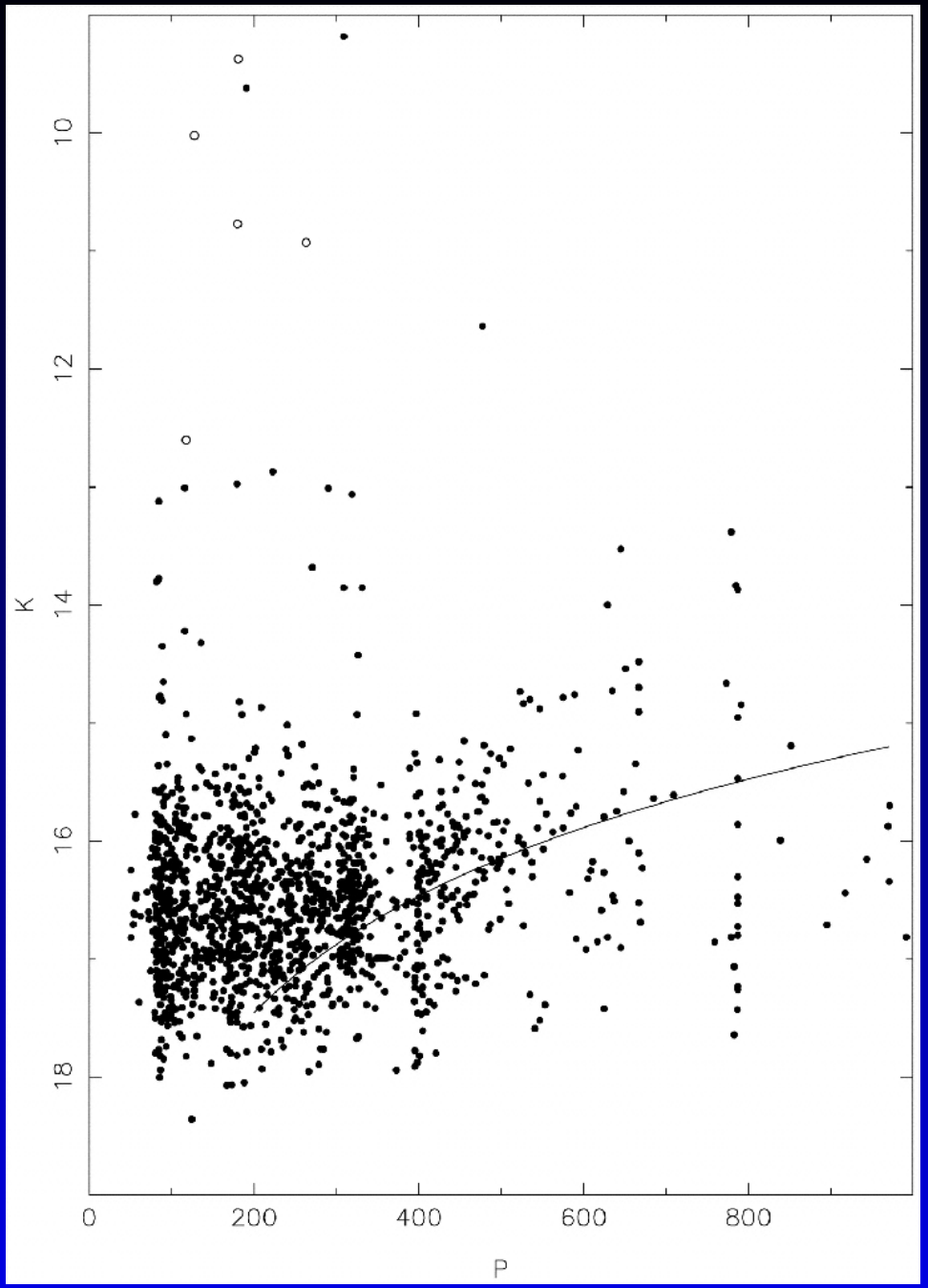
- MCs
  (Wood, Noda, Lebzelter, Cioni, Ita, Kiss & Bedding, Fraser, Raimundo, Groenewegen)
- Bersier & Wood (2002):
  85 LPV candidates in Fornax
- Gallart et al. (2004):
  6 LPV candidates in Phoenix
- Rejkuba (2004):
  240 well defined Miras in NGC 5128
- Snigula et al. (P54, 2006, 2004):
  11 / 2 / 52 / 0 LPV candidates in
  Leo A / GR 8 / Pegasus / DDO 210

Variability

- M31:
  Ansari et al. (2004); AGAPE, B, R,
  3 years, 40-80 epochs
  1579 variables in 10′x 14′ field

  Mould et al. (2004); I (6 years, 13-17 epochs),
  JHK
  1900 LPVs in 5 stripes of 10′x 60′

  Fliri et al. (2006); WeCAPP, R, I,
  3 years, 200-400 epochs,
  19000 R/SR LPVs in 16′x 16′ field



Mould et al. (2004)

How to identify late-type stars ?

- Narrow-band filters

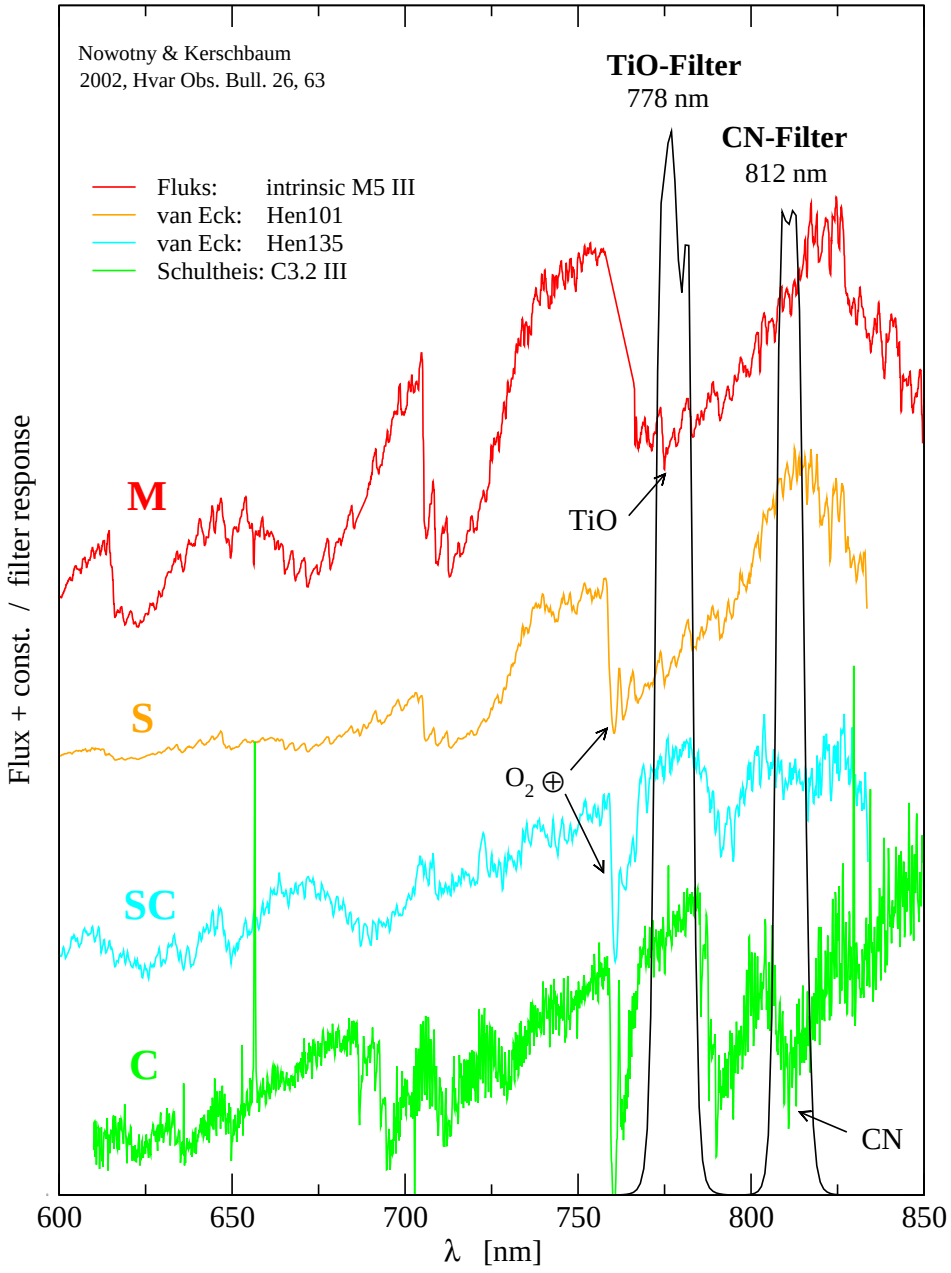
  Wing (1971), Palmer & Wing (1982)
  Richer et al. (1984); Aaronson et al. (1984)

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

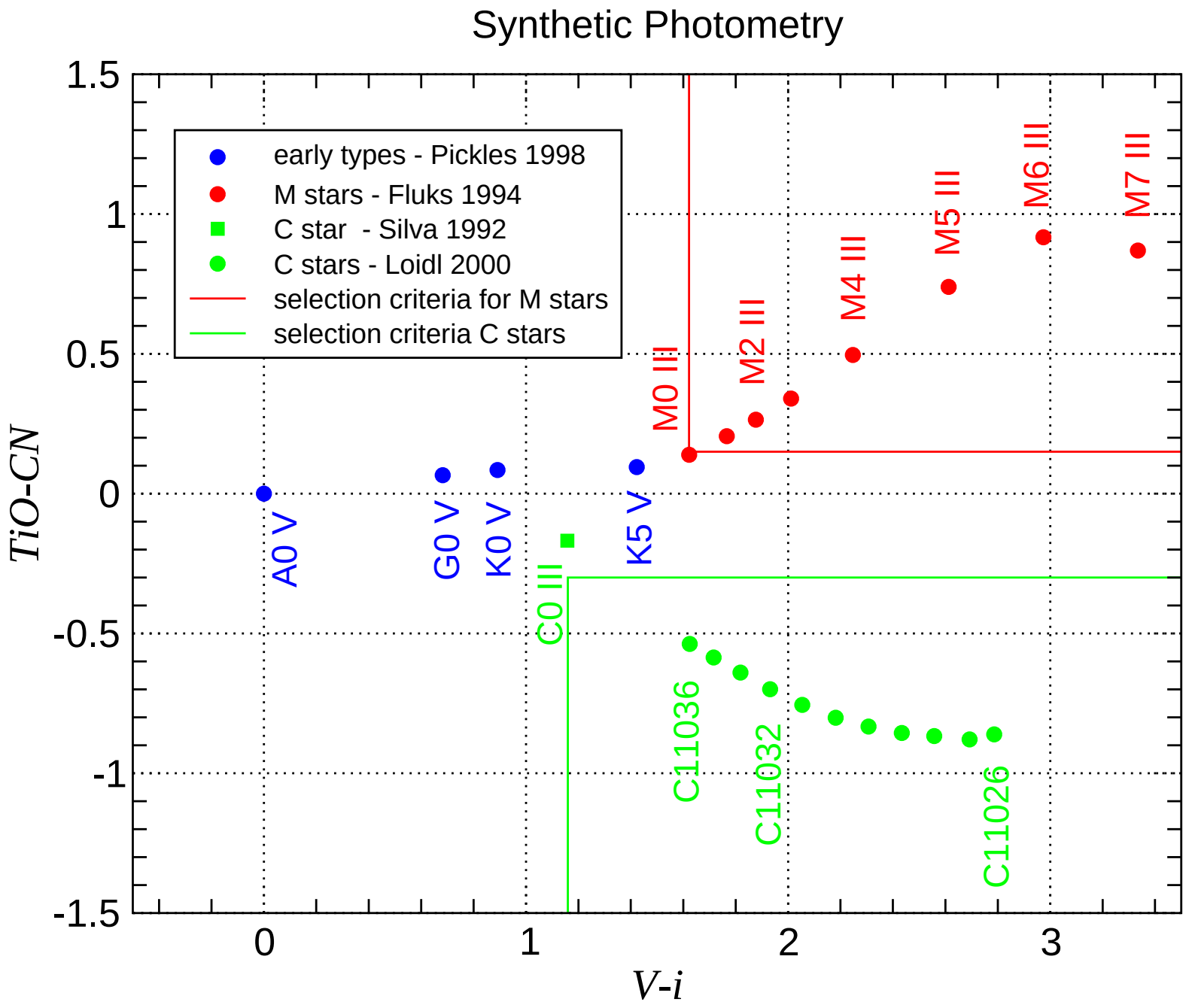
  advantage: spectroscopic identification

  disadvantage: foreground M-stars

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



Nowotny & Kerschbaum 2002



Nowotny & Kerschbaum 2002

Narrow-band surveys ($\geq$2004)

- Battinelli/Demers/LeTarte:

  DDO 190 (47), very outer disk of M31 (15), IC10 (676), NGC 147 (288), NGC 185 (145), WLM (149)

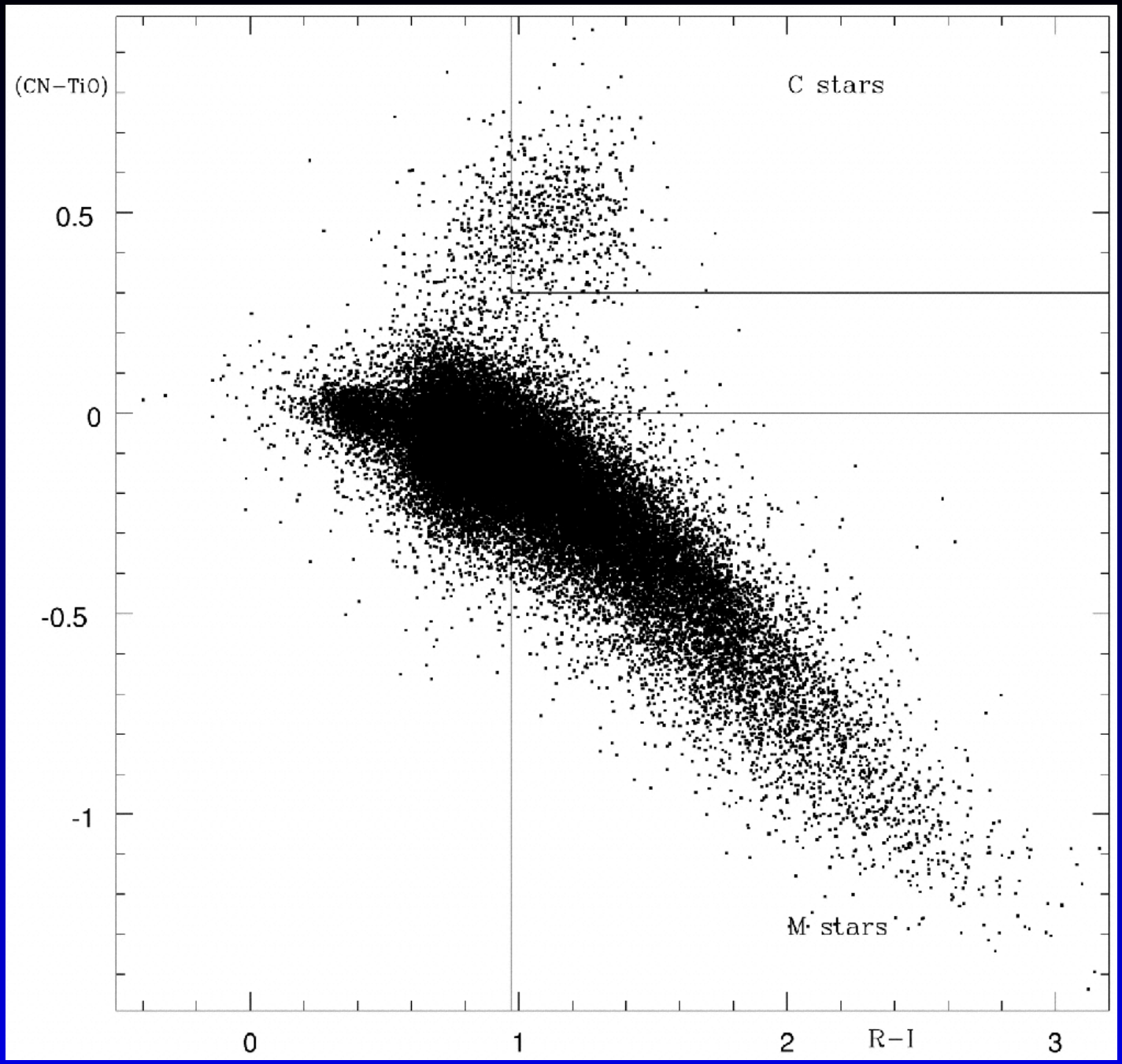
- Kerschbaum/Nowotny:

  And II (7), Leo I (40, 19 new), Leo II (11, 6 new), Draco (2, no new), M32 (51), Ursa Minor (data acquired)

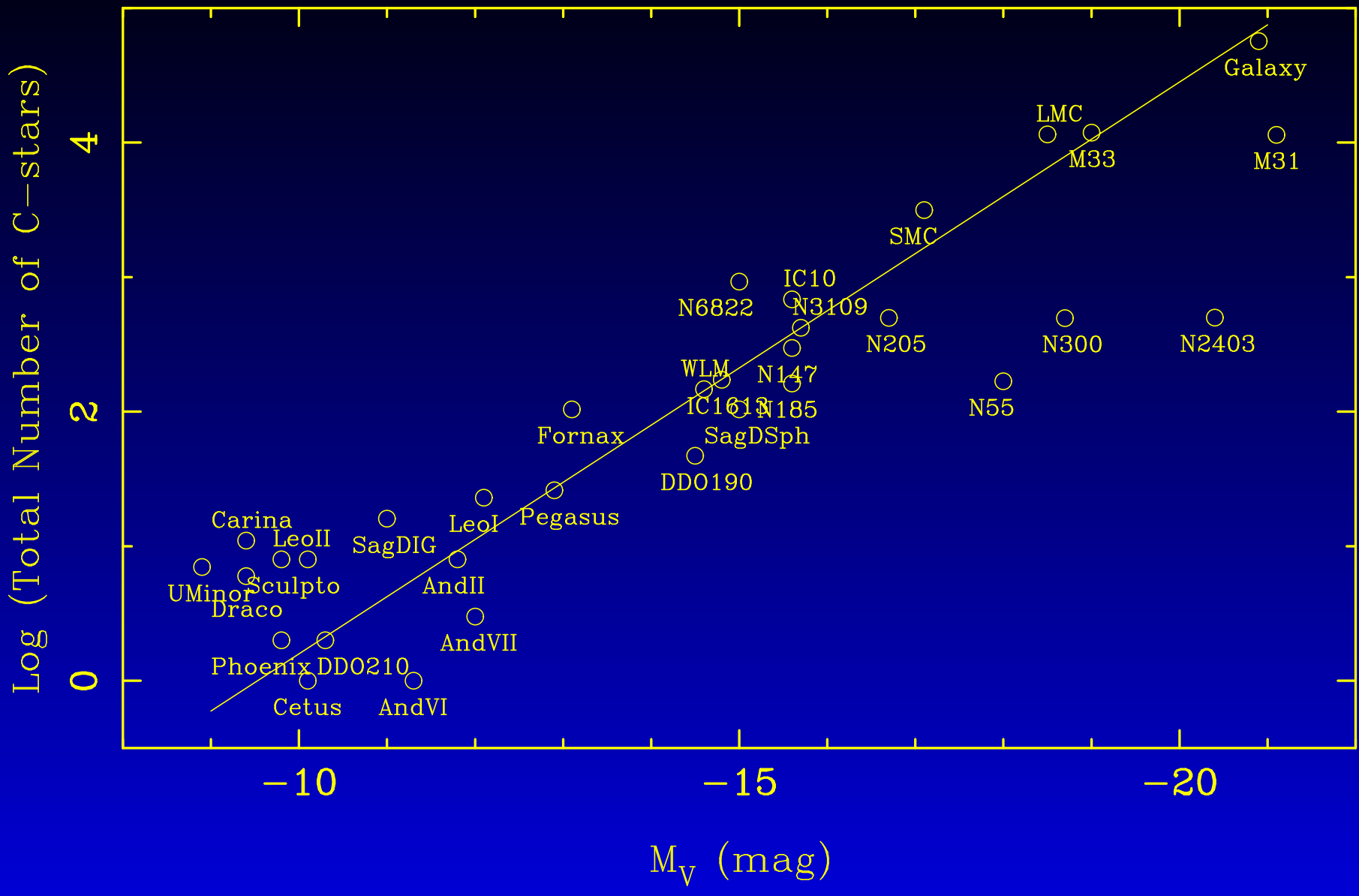
- Harbeck/Grebel/Gallagher:

  Cetus dSph (1),
  And III (0), V (0), VI (1), VII (3), IX (1?)

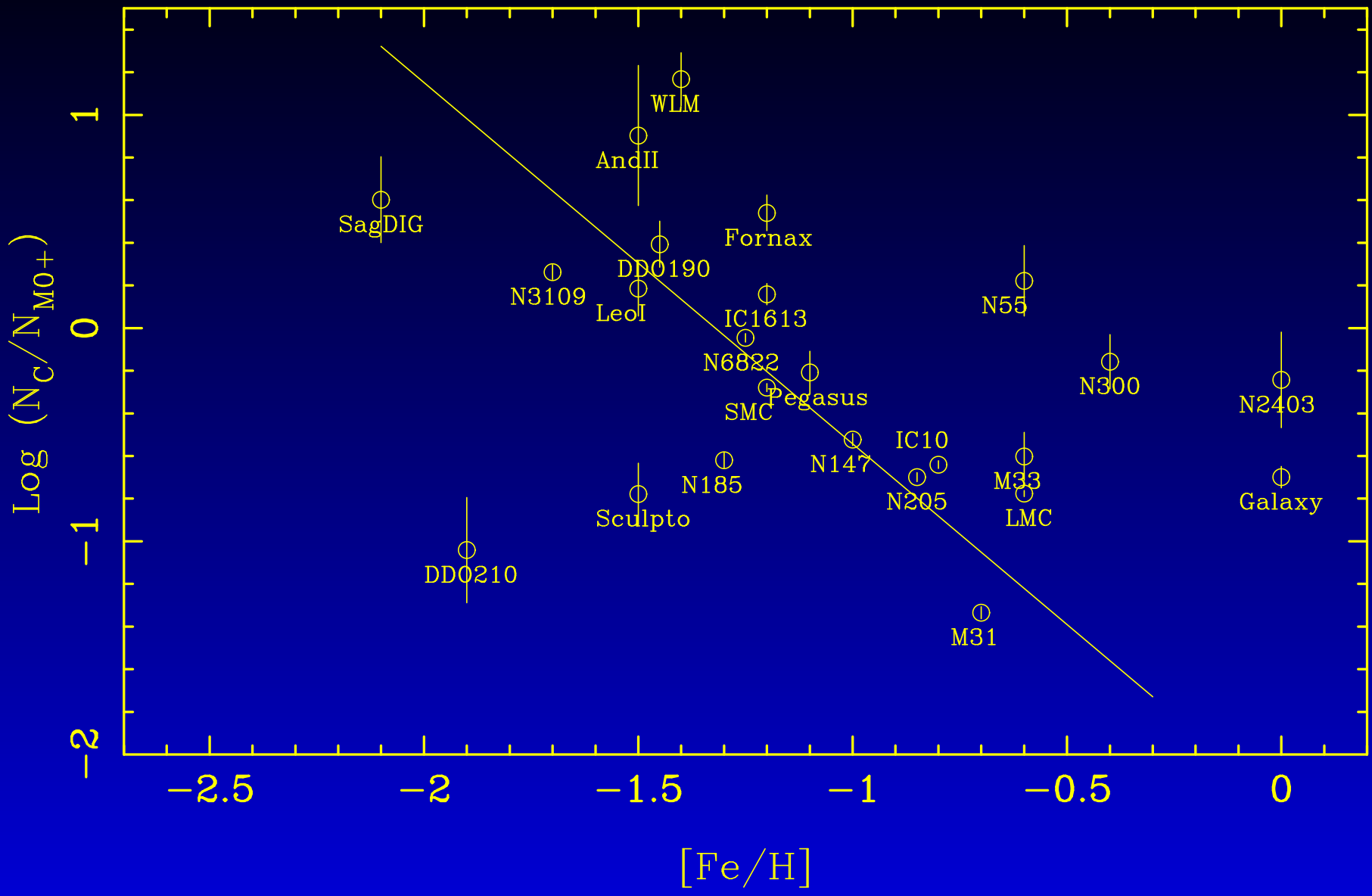
- Rowe et al. (2005): M33 (7900)



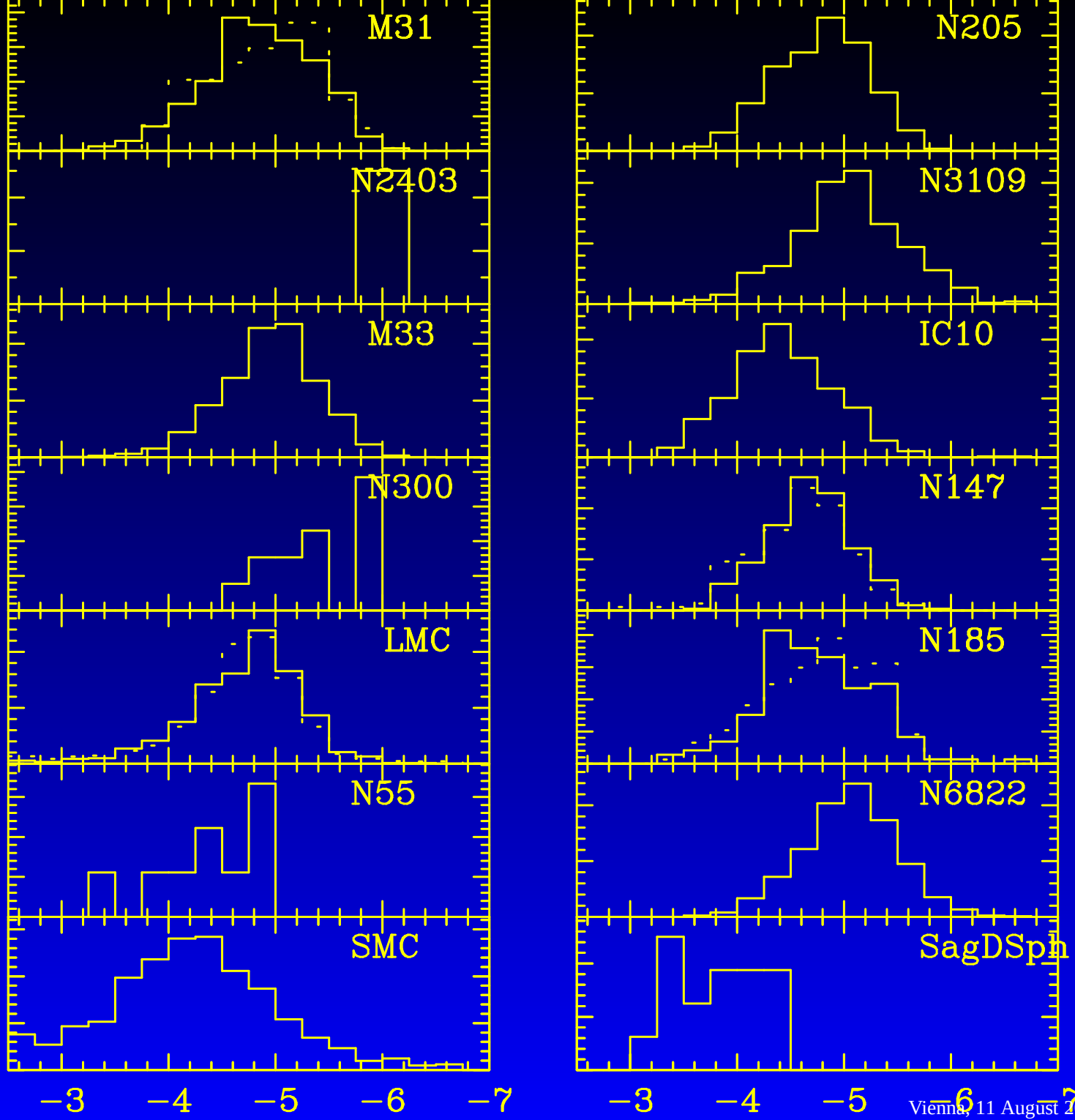
Demers et al. (2003) for NGC 205

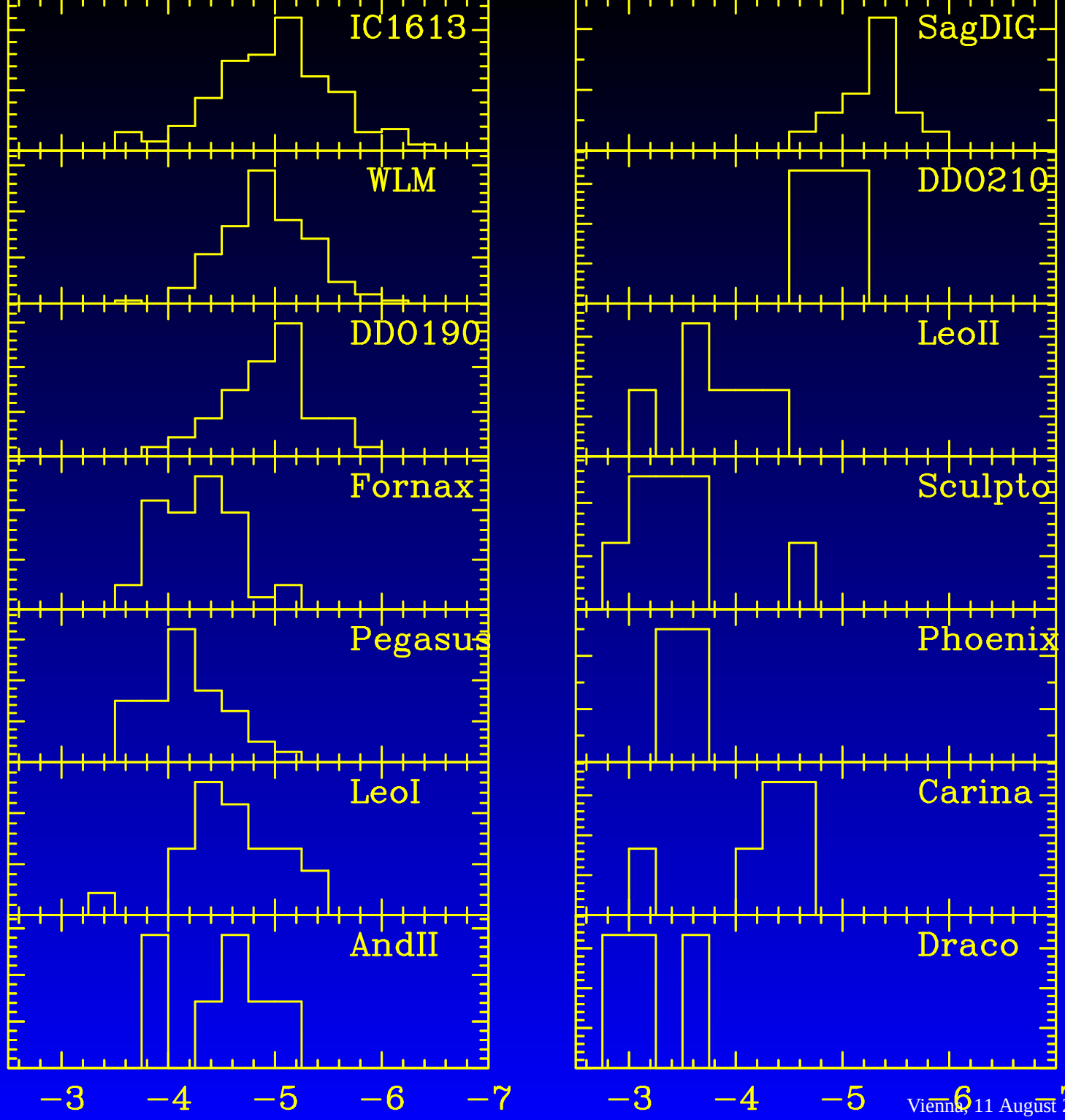


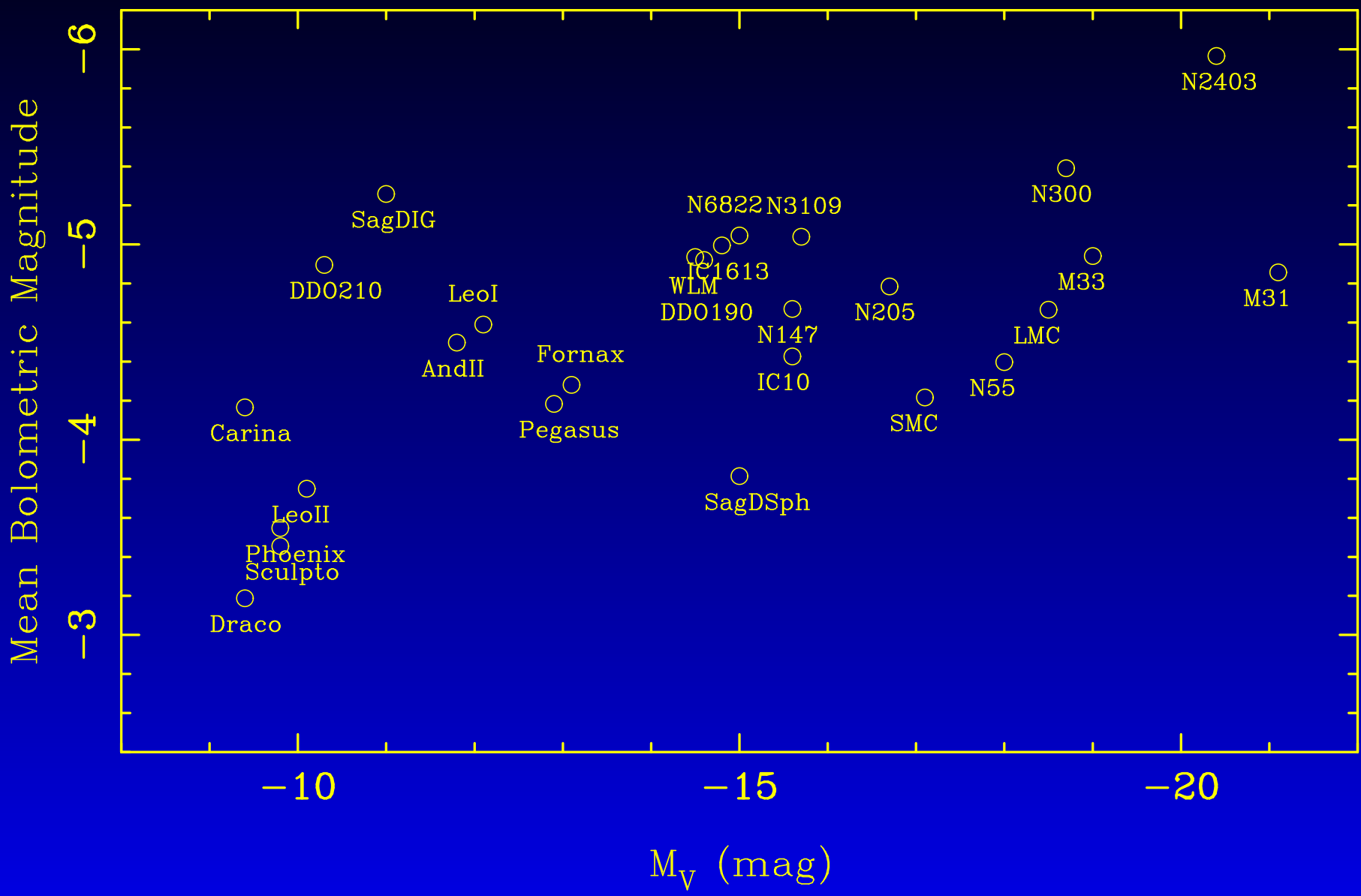
Fit from Battinelli & Demers (2005)

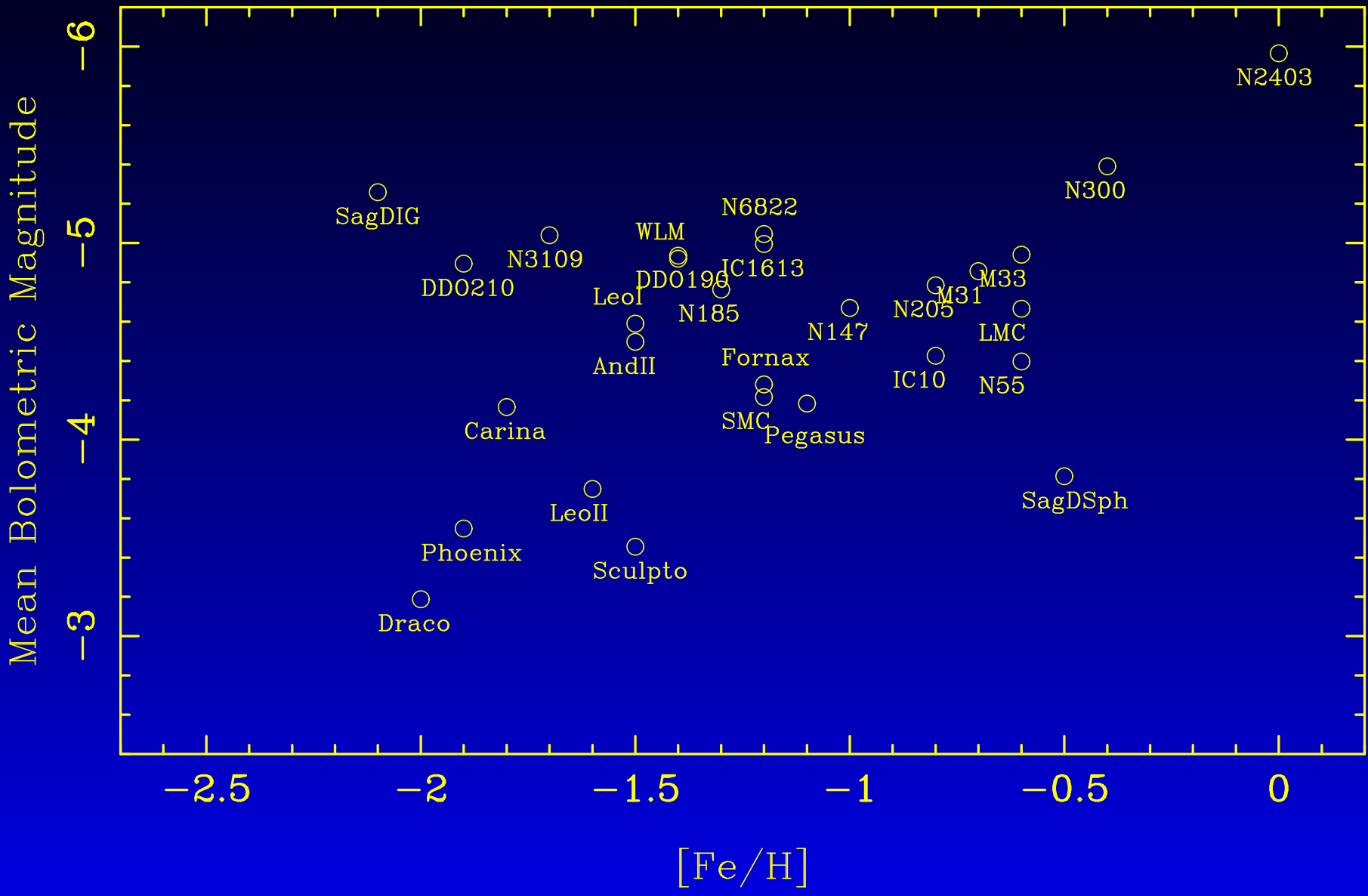


Fit from Battinelli & Demers (2005)

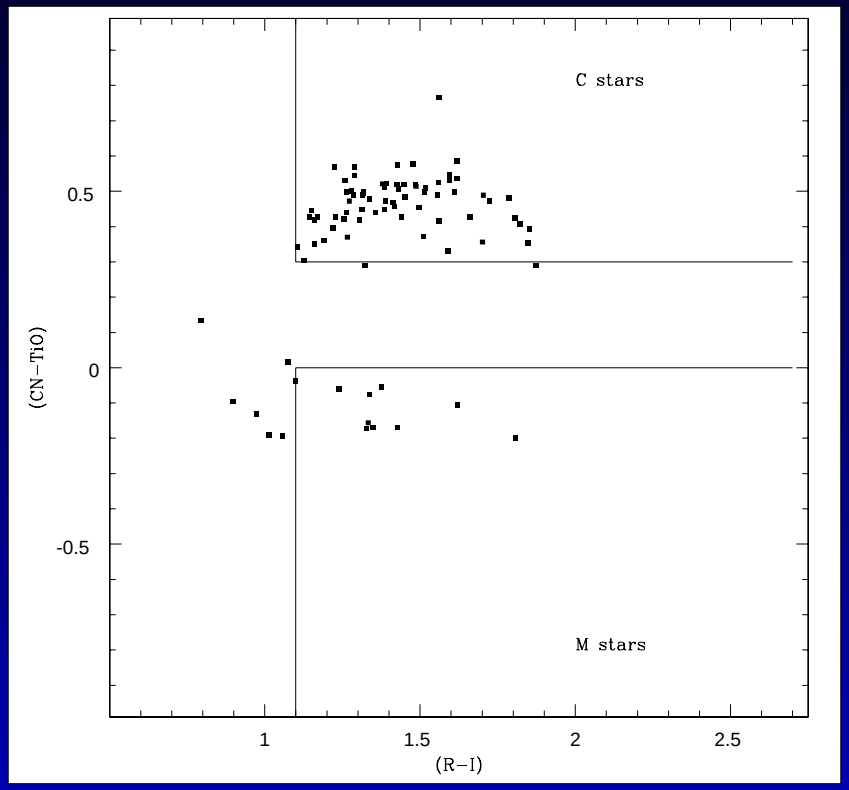

M31
N2403
M33
N300
LMC
N55
SMC
N205
N3109
IC10
N147
N185
N6822
SagDSph
−3
−4
−5
−6
−7
−3
−4
−5
−6
−7

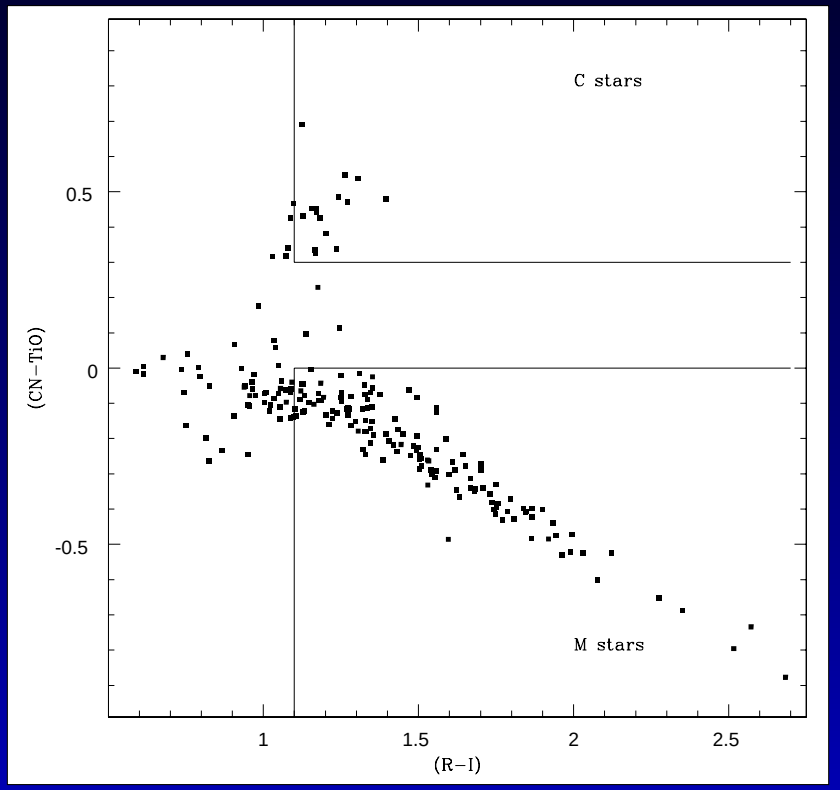

IC1613
WLM
DDO190
Fornax
Pegasus
LeoI
AndII
SagDIG
DDO210
LeoII
Sculpto
Phoenix
Carina
Draco
−3
−4
−5
−6
−7
−3
−4
−5
−6
−7


Mean Bolometric Magnitude
−3
−4
−5
−6
−10
−15
−20
M_V (mag)
N2403
N300
M33
M31
N6822
N3109
SagDIG
IC1613
WLM
DDO210
LeoI
DDO190
N205
N147
LMC
AndII
Fornax
IC10
N55
Carina
Pegasus
SMC
SagDSph
LeoII
Phoenix
Sculpto
Draco


Mean Bolometric Magnitude
−6
−5
−4
−3
−2.5
−2
−1.5
−1
−0.5
0
[Fe/H]
N2403
N300
SagDIG
N6822
WLM
N3109
IC1613
M33
DDO210
DDO190
M31
Leol
N185
N205
N147
LMC
AndII
Fornax
IC10
N55
Carina
SMC
Pegasus
SagDSph
LeoII
Phoenix
Sculpto
Draco

Narrow-band *vs.* $(J-K)$





NGC 6822 (Demers et al. 2006)
-of 85 C-star candidates from $(J-K)$, 69 are C-stars
-of 207 O-star candidates from $(J-K)$, 20 are C-stars

Narrow-band *vs.* $(J - K)$

NGC 6822

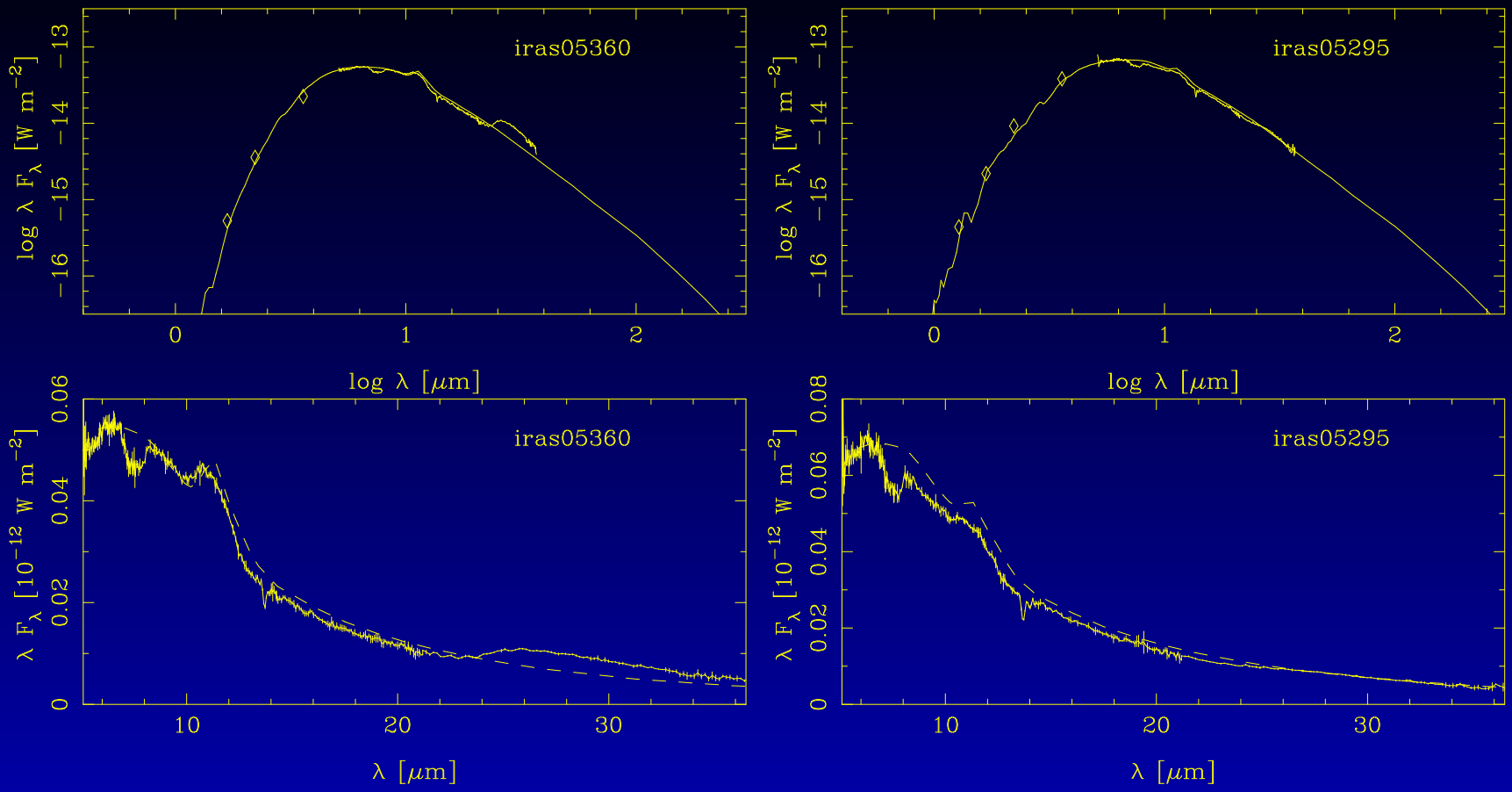
- Kang et al.: 6.3′ x 3.6′ 141 C-stars, C/M = 0.27
- Cioni et al.: 20′ x 20′ 1511 C-stars, C/M = 0.32
- NB-filters: 42′ x 28′ 904 C-stars, C/M = 1.0 ± 0.2

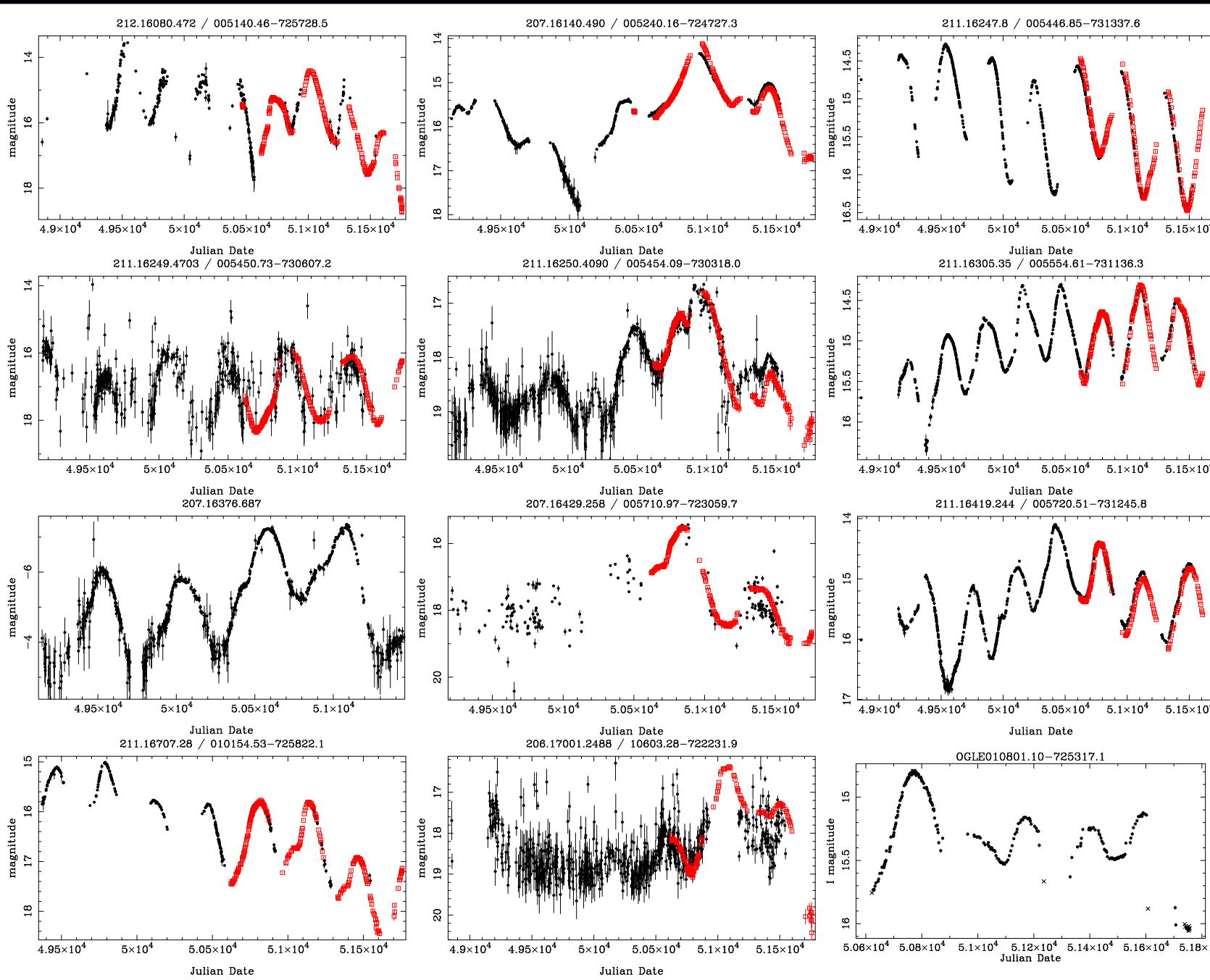
Spitzer

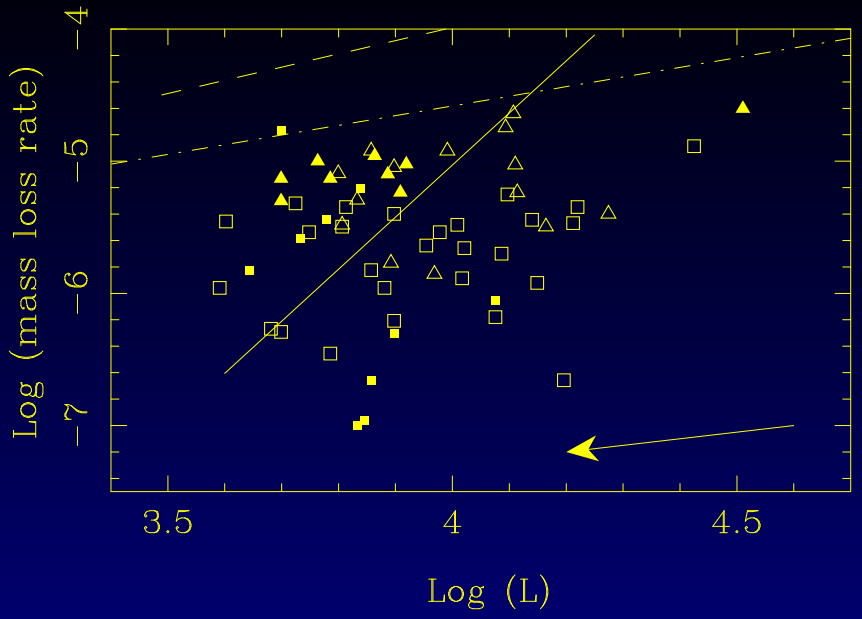
- Spitzer IRS 5-38 μm spectra of 60 carbon stars in the SMC and LMC

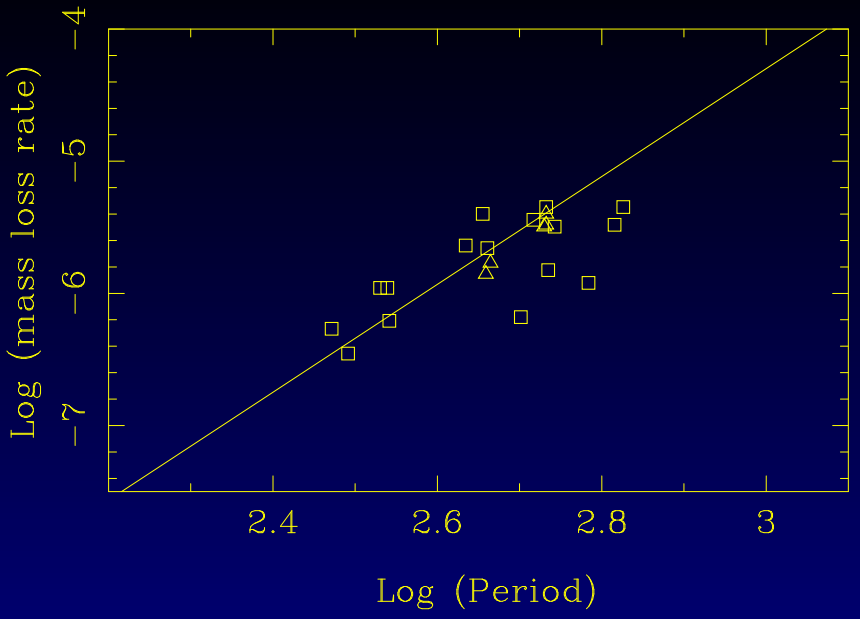
  General Observing programmes
  3505 (PI. P.R. Wood) and 3277 (PI. M. Egan)

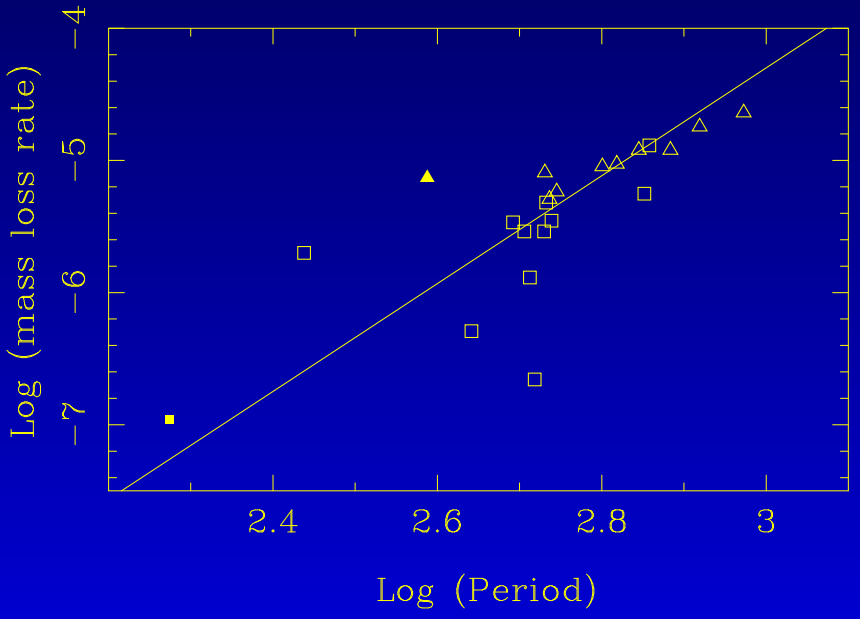
  Zijlstra et al. (2006), Lagadec et al. (2006), Sloan et al. (2006), Matsuura et al. (2006)
- quasi-simultaneous $JHKL$ photometry


iras05360
iras05295
log λ Fλ [W m−2]
log λ [μm]
λ Fλ [10−12 W m−2]
λ [μm]


212.16080.472 / 005140.46−725728.5
207.16140.490 / 005240.16−724727.3
211.16247.8 / 005446.85−731337.6
211.16249.4703 / 005450.73−730607.2
211.16250.4090 / 005454.09−730318.0
211.16305.35 / 005554.61−731136.3
207.16376.687
207.16429.258 / 005710.97−723059.7
211.16419.244 / 005720.51−731245.8
211.16707.28 / 010154.53−725822.1
206.17001.2488 / 10603.28−722231.9
OGLE010801.10−725317.1
magnitude
I magnitude
Julian Date







SMC= squares; LMC= triangles
open= Mira-like pulsation; filled= SR-like pulsation
solid line= Galactic C-miras

NIR spectroscopy

- Groenewegen & Lançon

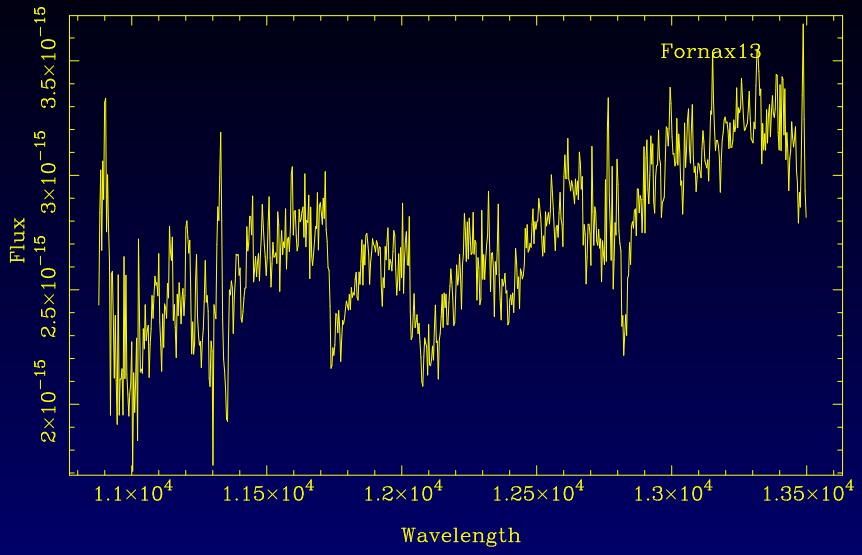
  ISAAC LR J+H band spectroscopy

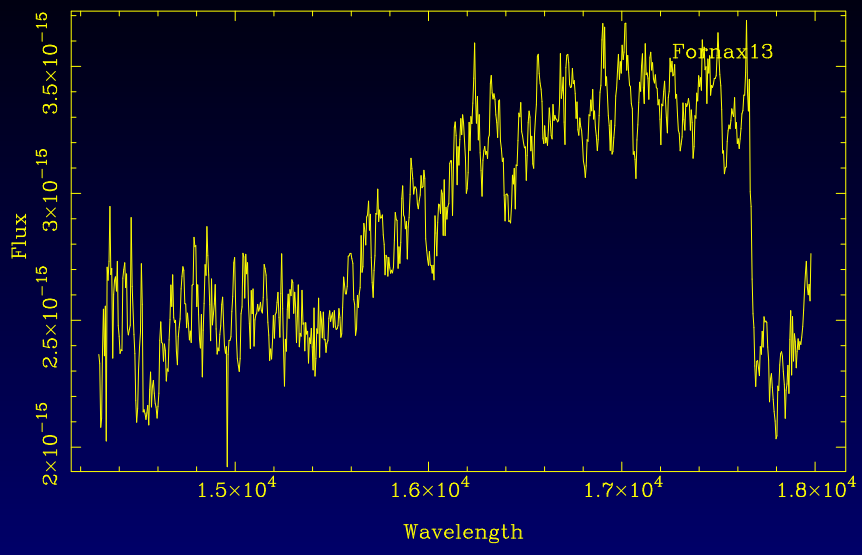
  AGB candidates selected from 2MASS ($J-K>1.22$)

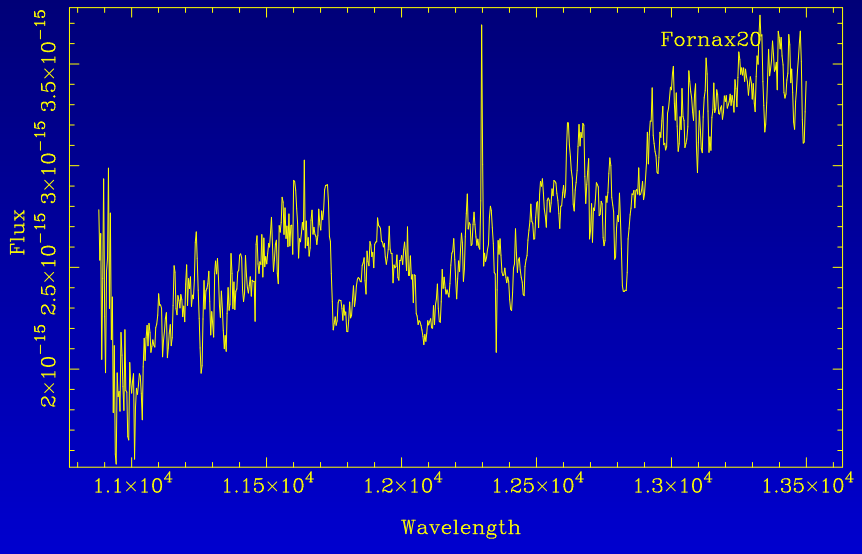
  Fornax (11 C, 15 non-C), Sculptor (1 C, 6 non-C)

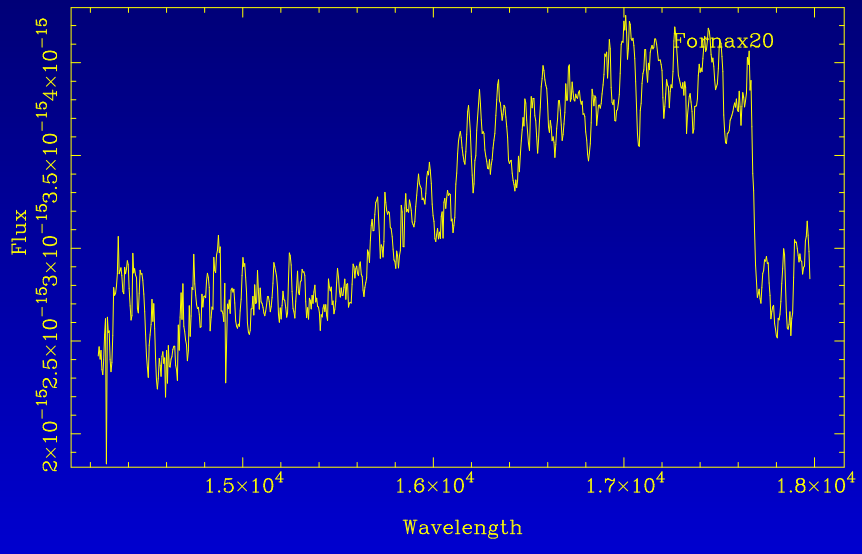
  all stars that have $J-K>1.65$ and $M_{\rm bol}<-4.1$ are C-stars

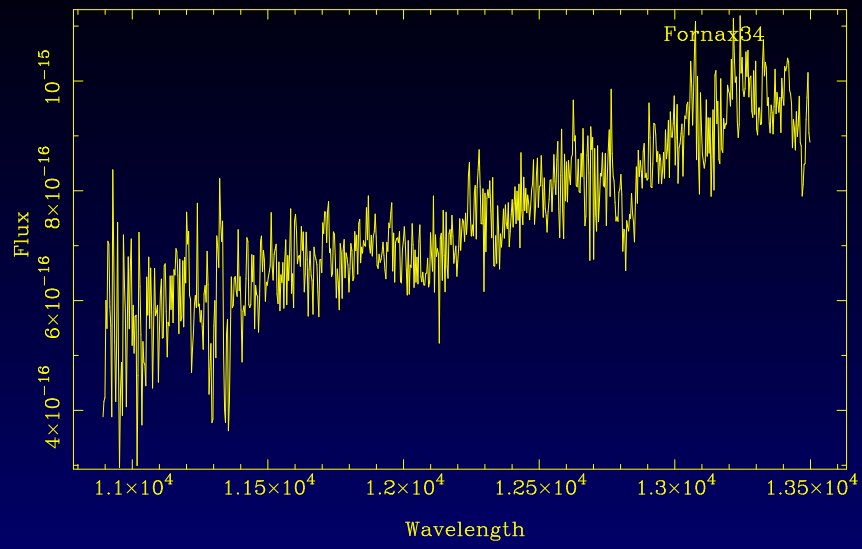
  all non-C stars have $J-K<1.65$ and $M_{\rm bol}>-3.4$

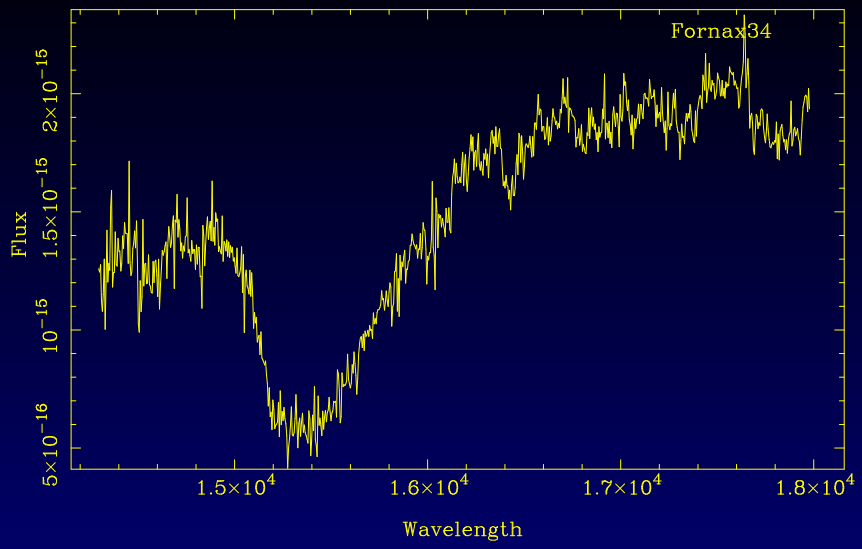

Fornax13
Flux
2×10^-15
2.5×10^-15
3×10^-15
3.5×10^-15
1.1×10^4
1.15×10^4
1.2×10^4
1.25×10^4
1.3×10^4
1.35×10^4
Wavelength

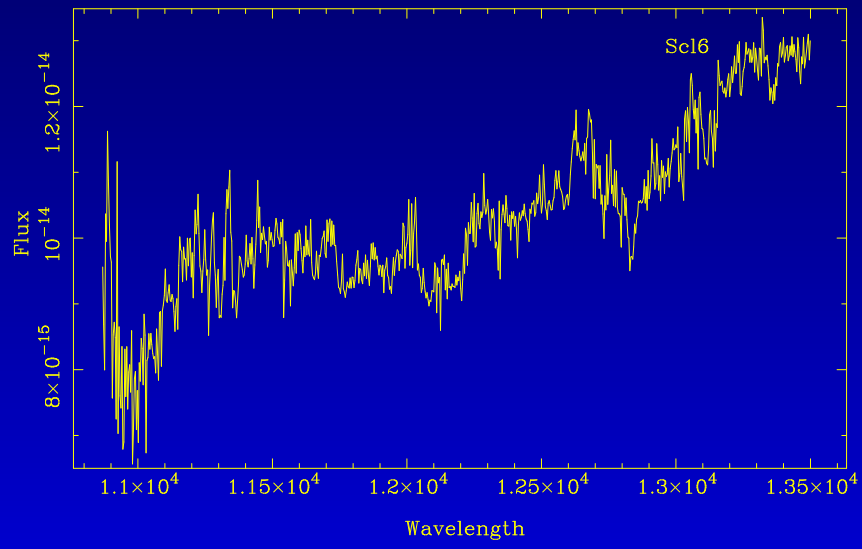

Fornax13
Flux
2×10^-15
2.5×10^-15
3×10^-15
3.5×10^-15
1.5×10^4
1.6×10^4
1.7×10^4
1.8×10^4
Wavelength

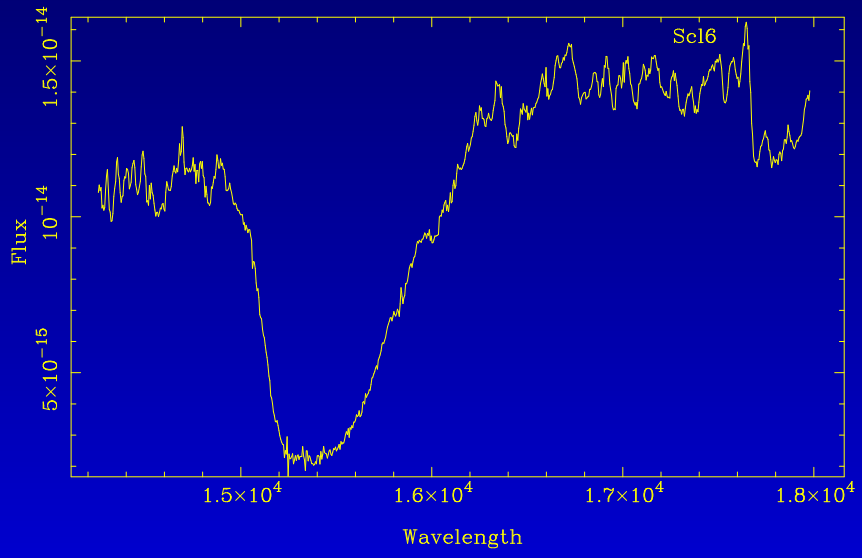

Fornax20
Flux
2×10^-15
2.5×10^-15
3×10^-15
3.5×10^-15
1.1×10^4
1.15×10^4
1.2×10^4
1.25×10^4
1.3×10^4
1.35×10^4
Wavelength


Fornax20
Flux
2×10^-15
2.5×10^-15
3×10^-15
3.5×10^-15
4×10^-15
1.5×10^4
1.6×10^4
1.7×10^4
1.8×10^4
Wavelength


Fornax34
Flux
4×10^{-16}
6×10^{-16}
8×10^{-16}
10^{-15}
1.1×10^{4}
1.15×10^{4}
1.2×10^{4}
1.25×10^{4}
1.3×10^{4}
1.35×10^{4}
Wavelength


Fornax34
Flux
5×10^{-16}
10^{-15}
1.5×10^{-15}
2×10^{-15}
1.5×10^{4}
1.6×10^{4}
1.7×10^{4}
1.8×10^{4}
Wavelength


Scl6
Flux
8×10^{-15}
10^{-14}
1.2×10^{-14}
1.1×10^{4}
1.15×10^{4}
1.2×10^{4}
1.25×10^{4}
1.3×10^{4}
1.35×10^{4}
Wavelength


Scl6
Flux
5×10^{-15}
10^{-14}
1.5×10^{-14}
1.5×10^{4}
1.6×10^{4}
1.7×10^{4}
1.8×10^{4}
Wavelength

Chemical abundances

- de Laverny et al. (2006):
  VLT/UVES of 1 SMC, 2 SagDSph C-stars
  C/O = 1.05 - 1.20, [s/M]= +1

- Wahlin et al. (2006): VLT/ISAAC of
  50 MC, Scl, Car, For DSph C-stars

  LMC C/O larger than Galactic stars

Conclusions

- NB-Surveys of LG are fairly complete

  Missing: Fornax dSph* (140), LGS3 (620), Leo A* (800), Sextans B* (1320), Sextans A* (1440), IC 5152 (1700), GR 8 (2200)

  NGC 55* (2200), NGC 300* (2200), NGC 2403* (3600)

  Limit: DDO190 at 2.8 Mpc, but crowding (NGC 3109 at 1.3 Mpc)

  SOAR (4.1m, 5.2′ FoV)
  CFHT (3.6m, 42 x 28′ FoV)
  WIYN (3.5m, 9.6′ FoV)
  TNG (3.5m, 9.4′ FoV)

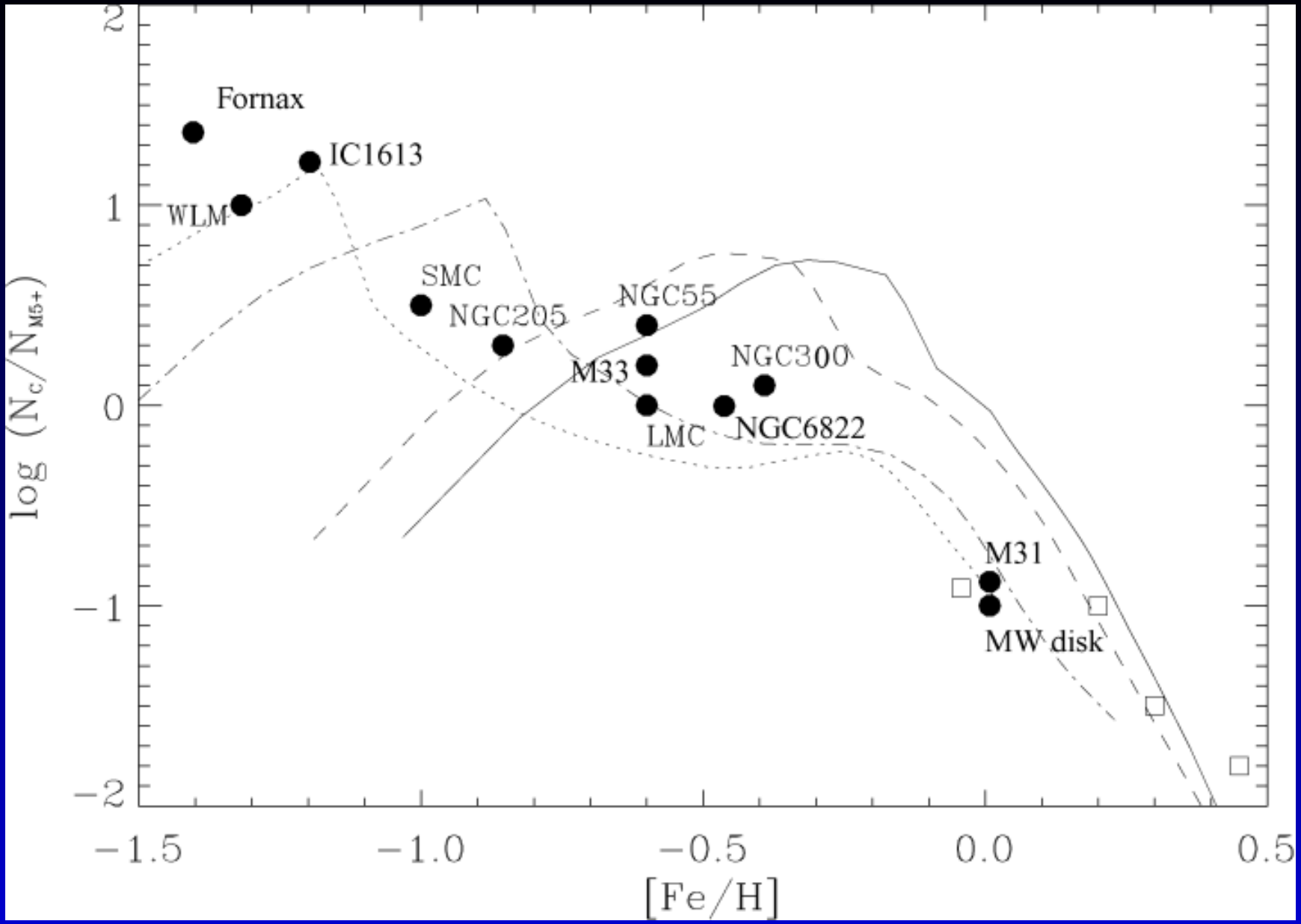
Conclusions

- Infrared AGB stars: many more than expected ?

  $(J - K)$, Spitzer IRAC, *vs.* narrow-band surveys

  Mass loss at low metallicity ?

- An evolutionary picture ?



Mouhcine & Lançon (2003)
(Sa = solid ; dashed= Sb ; dot-dash = Sc ; dot = Irr)

Future

- High-resolution optical & IR spectrographs: C/O ratio's
- super-MACHO, OGLE-III, EROS

  IRSF-SIRIUS on LG

  LSST
- ALMA: CO lines (expansion velocities, dust-to-gas ratios)