# Populations of AGB stars and LPVs in the Galaxy and Local Group

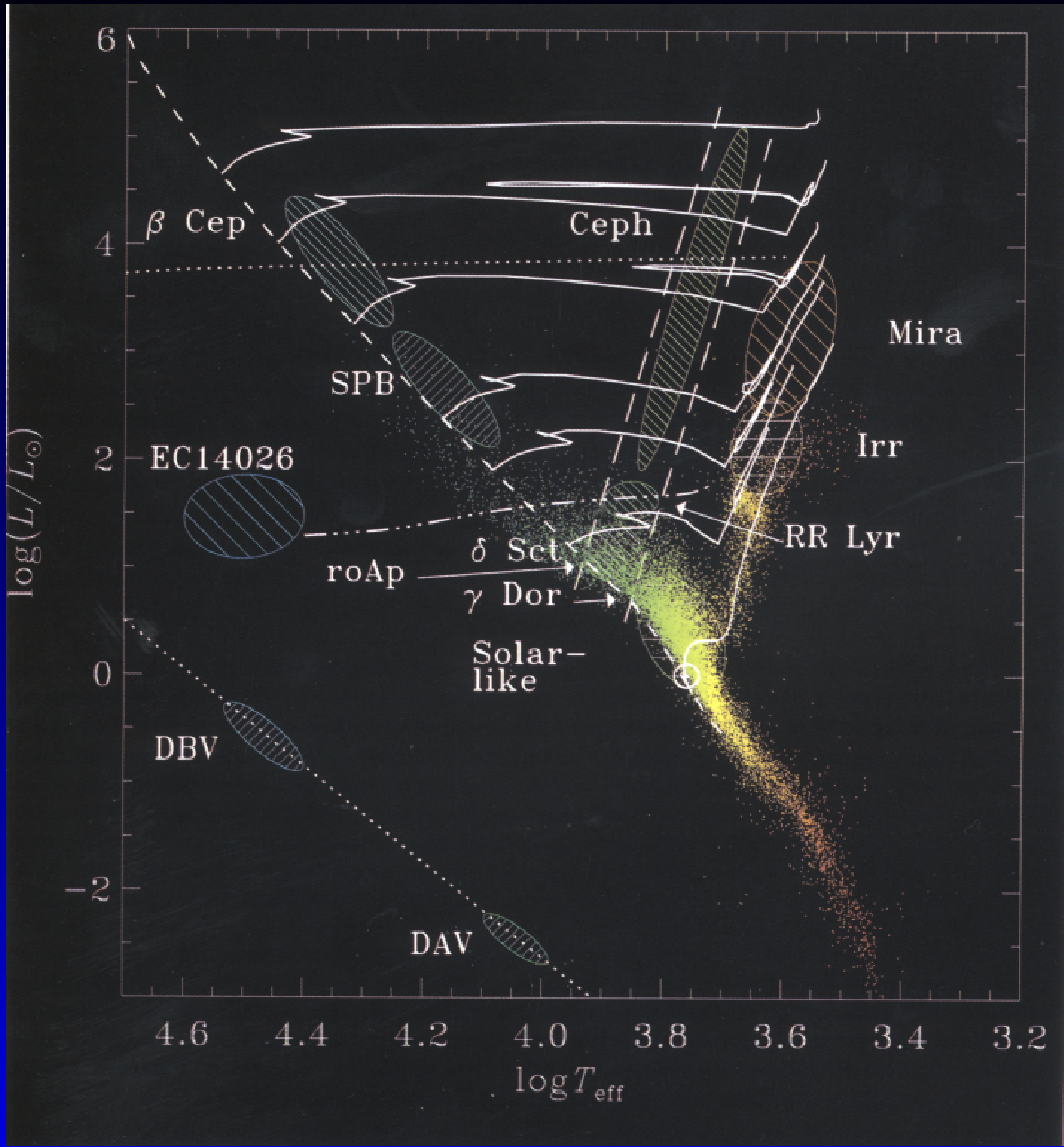
Martin Groenewegen

K.U.Leuven

# Overview

- Late-type stars
- How to find them?

  Infrared colours
  Variability
  Chemistry
- MSX / 2MASS (Galaxy / MCs)
- Micro-lensing surveys (GB / MCs)
- Narrow-band filter surveys (LG)




# Evolutionary Phases

# Late-type stars

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

Depends on:
-initial mass
-metallicity
-mass loss
-dredge-up
-Hot Bottom Burning

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

# How to identify late-type stars ?

Low effective temperatures + mass loss rate

- Infra-red broadband photometry

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

  Advantage:
  Very red colours traces different population

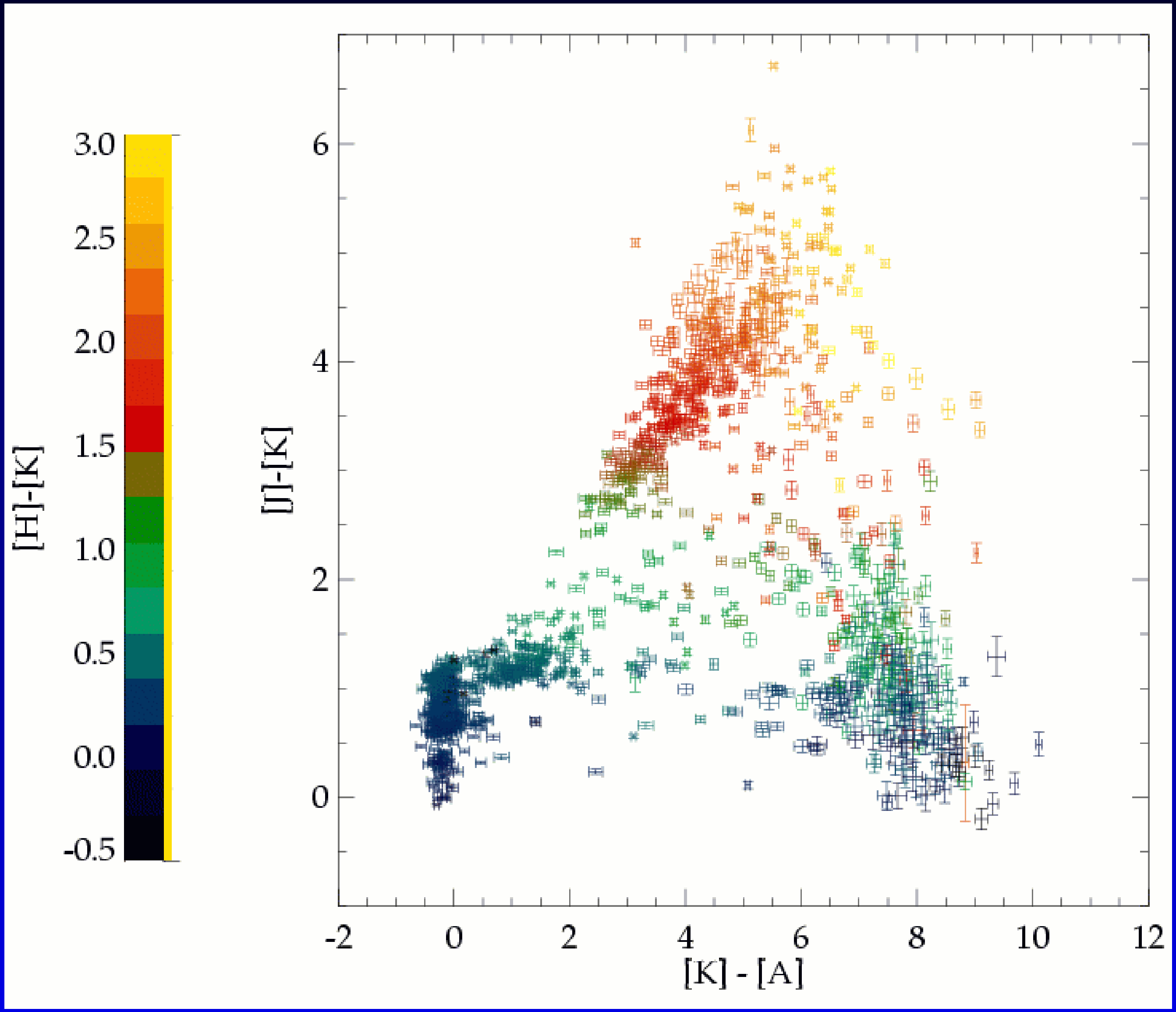
  MSX / 2MASS

# MSX

Midcourse Space Experiment (SPIRIT III)

- LMC (Egan et al. 2001): $A$ (8.3 $\mu$m) 0.05 Jy, 1806 $\rightarrow$ 1664 2MASS

# MSX




Egan et al. 2001

# MSX

Midcourse Space Experiment (SPIRIT III)

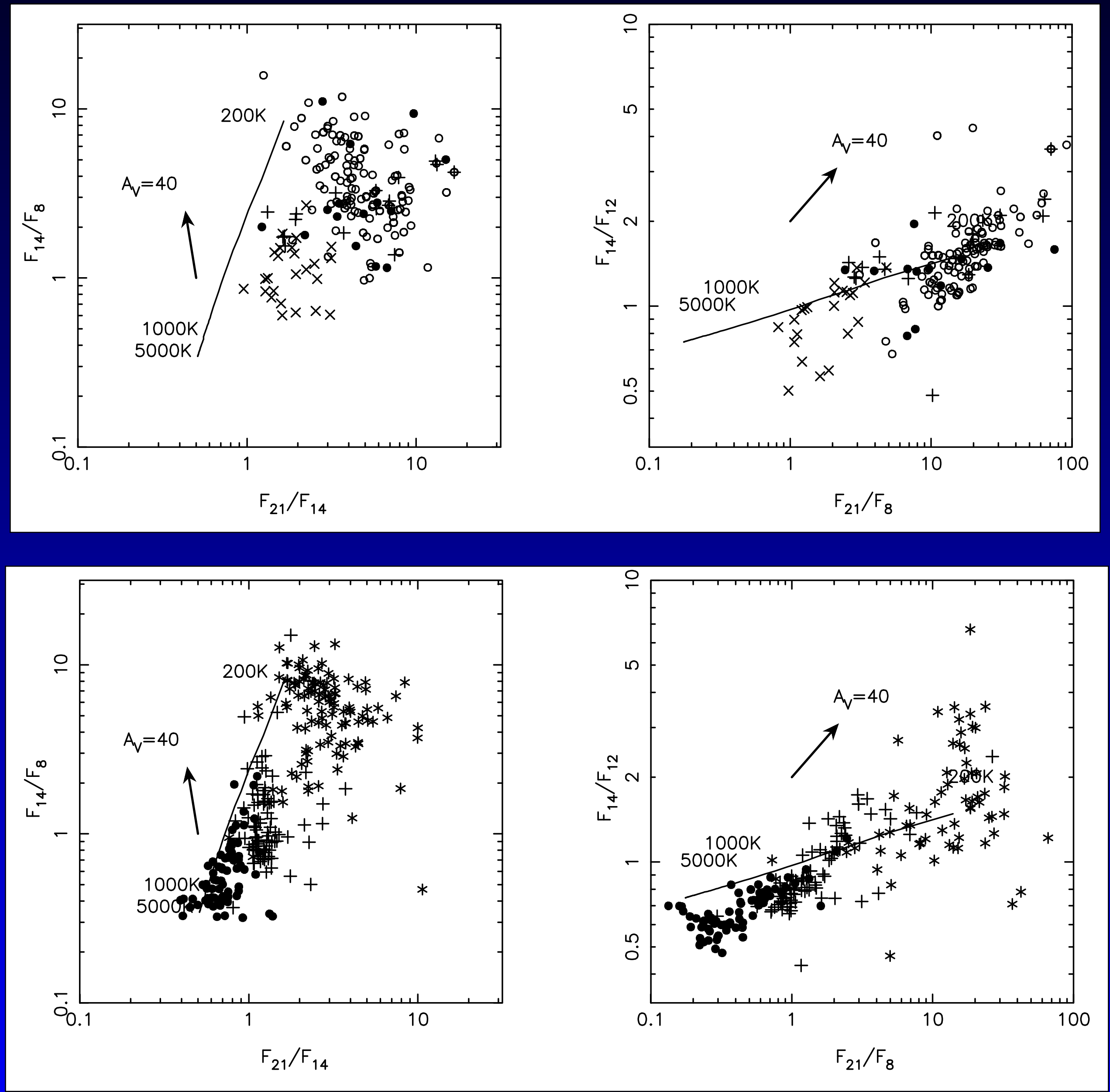
- LMC (Egan et al. 2001): $A$ (8.3 $\mu$m) 0.05 Jy, 1806 $\longrightarrow$ 1664 2MASS

- Galactic Plane ($\mid b \mid < 5^o$), $\sim$320 000

  Lumsden et al. (2002; MYSO):
  14 900 MSX $ADE$, 9000 also IRAS 12 $\mu$m
  also 2MASS + Gezari et al. compilation

  Ortiz et al. (2005):
  correlated catalogs of KNOWN OH/IR,
  C-stars with CO observations, post-AGB, PNe
  AND 2MASS: 400 objects

# MSX



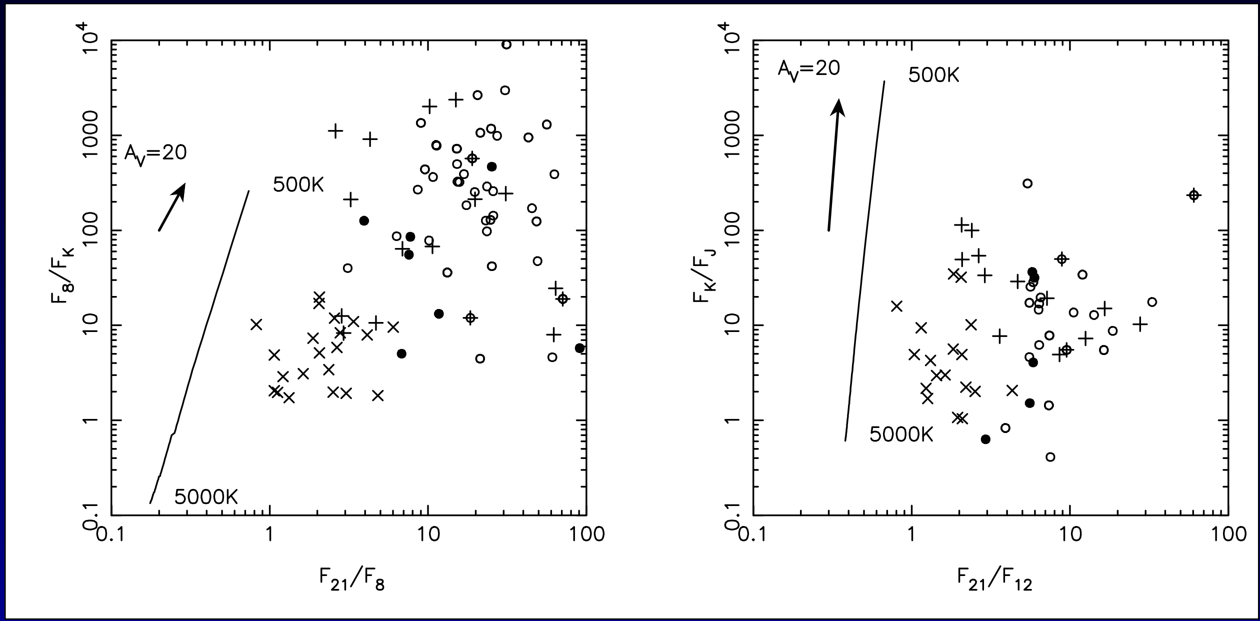

Young stars:

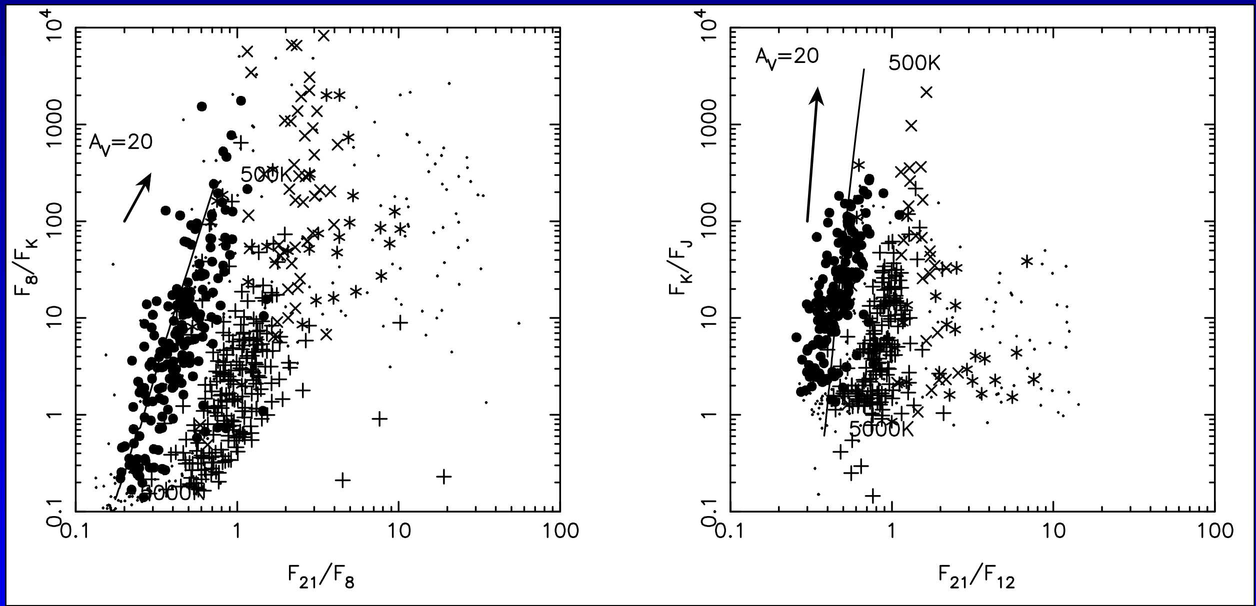
HAe/Be= x
MYSO= +
compact
HII = o

known spectral type:

C-stars = ●
OH/IR = +
PNe = *

# MSX




Young stars:

HAe/Be= x
MYSO= +
compact HII = o

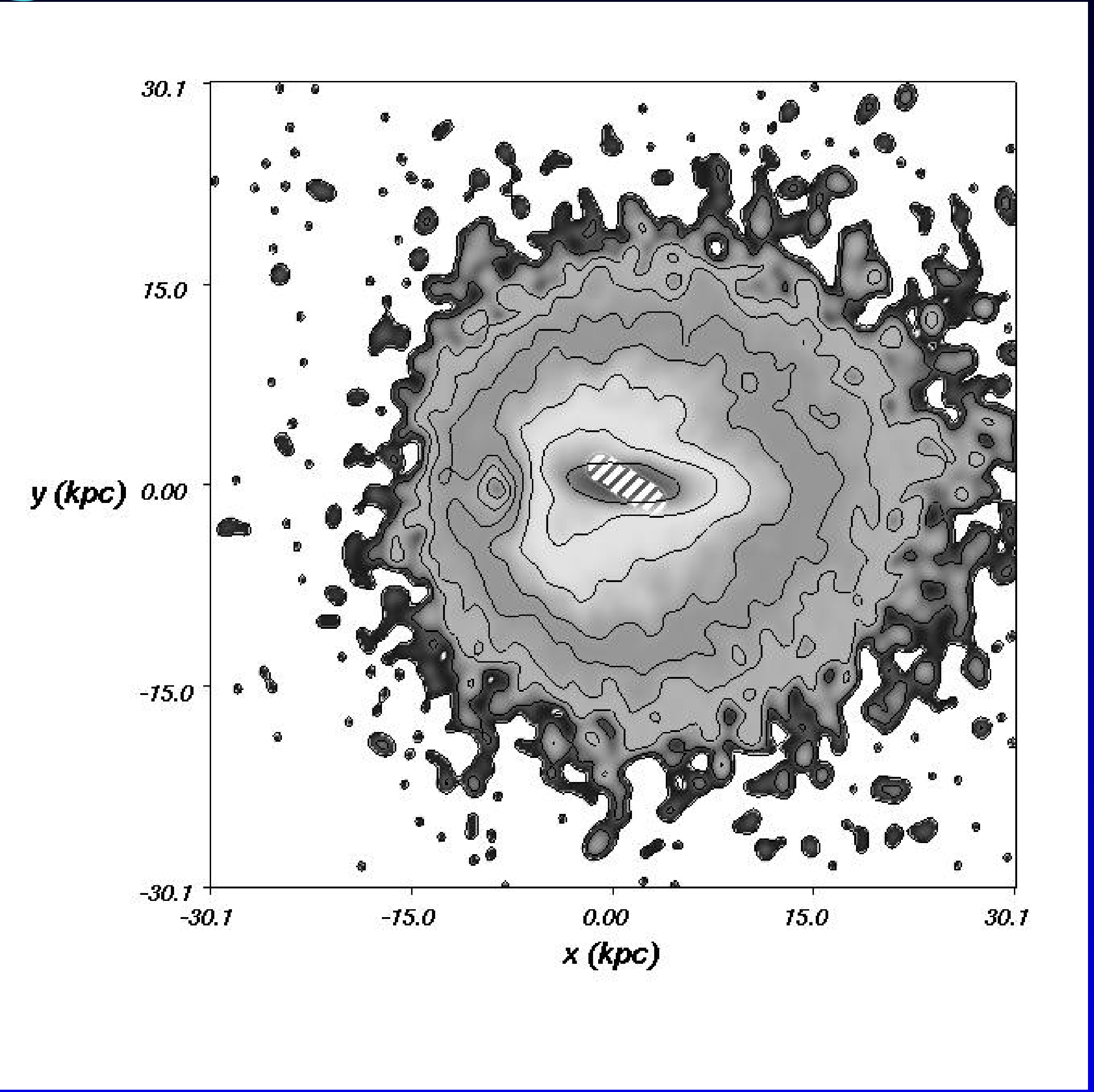
LRS:

4n = ●
2n = +
3n = x
PAH = *
other = .

# 2 Micron All-Sky Survey

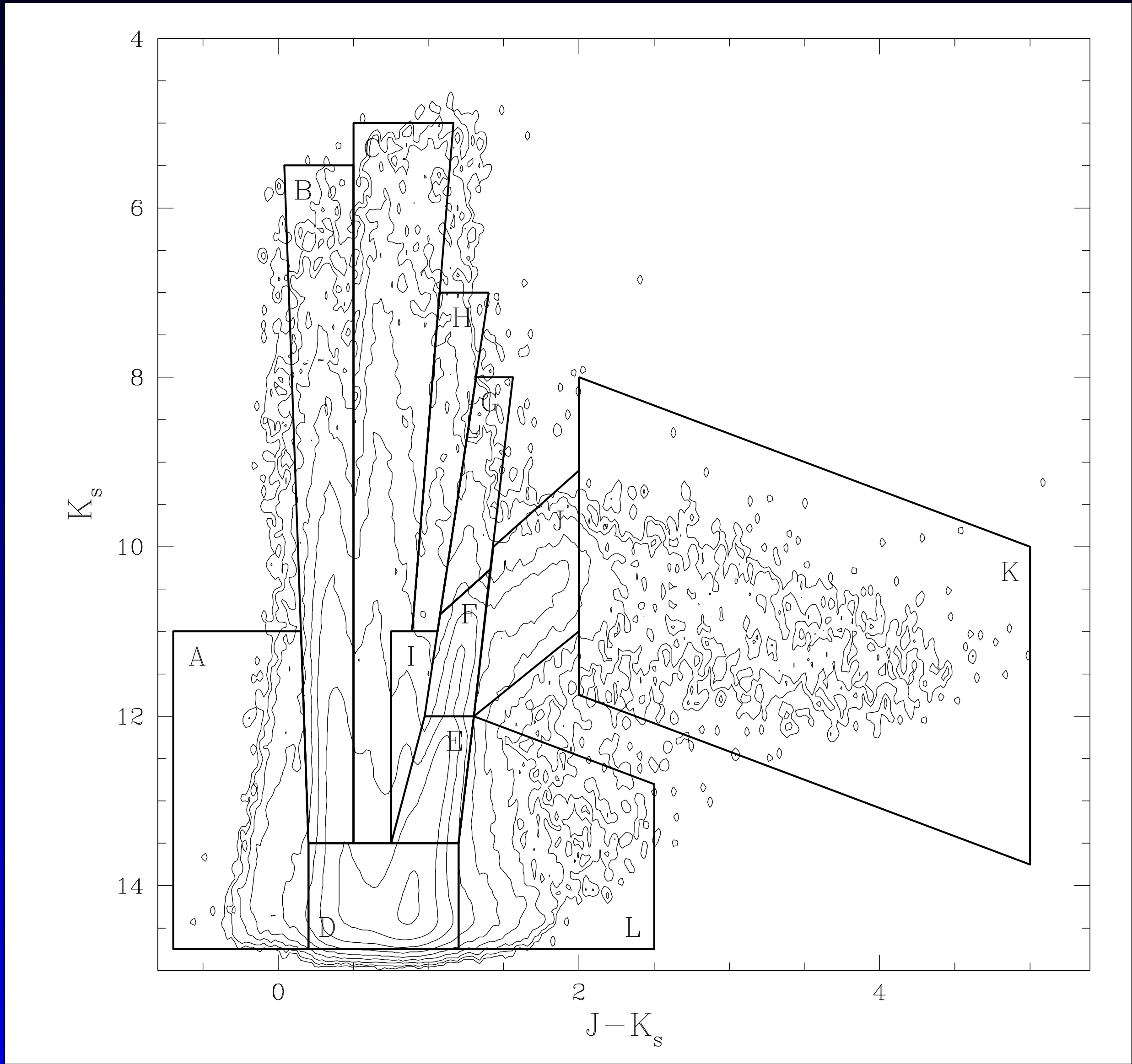
- FHLC stars:
  Liebert et al. (2000), Mauron et al. (2004; 2IDR).
  Selection based on known C-stars at $\mid b \mid > 30^o$.
  Mauron et al.: 200 ‘best’ candidates $\rightarrow$ 97 spectra
  $\rightarrow$ 30 C-stars (1 known, 1 Fornax, 1 Sculptor)
  8 have PM. Argue for N-type, not C-dwarfs
  8-80 kpc, 50% related to Sgr stream
- Cole & Weinberg (2002)
  $J - K > 2$. Argue for IR C-stars, contamination
  M-SG, OH/IR
  $M_K = f(J - K)$
  Age bar: ‘likely’ $< 3$ Gyr

# 2MASS




Galaxy. Cole & Weinberg (2002)

# 2MASS




LMC. Nikolaev & Weinberg 2000, 2001

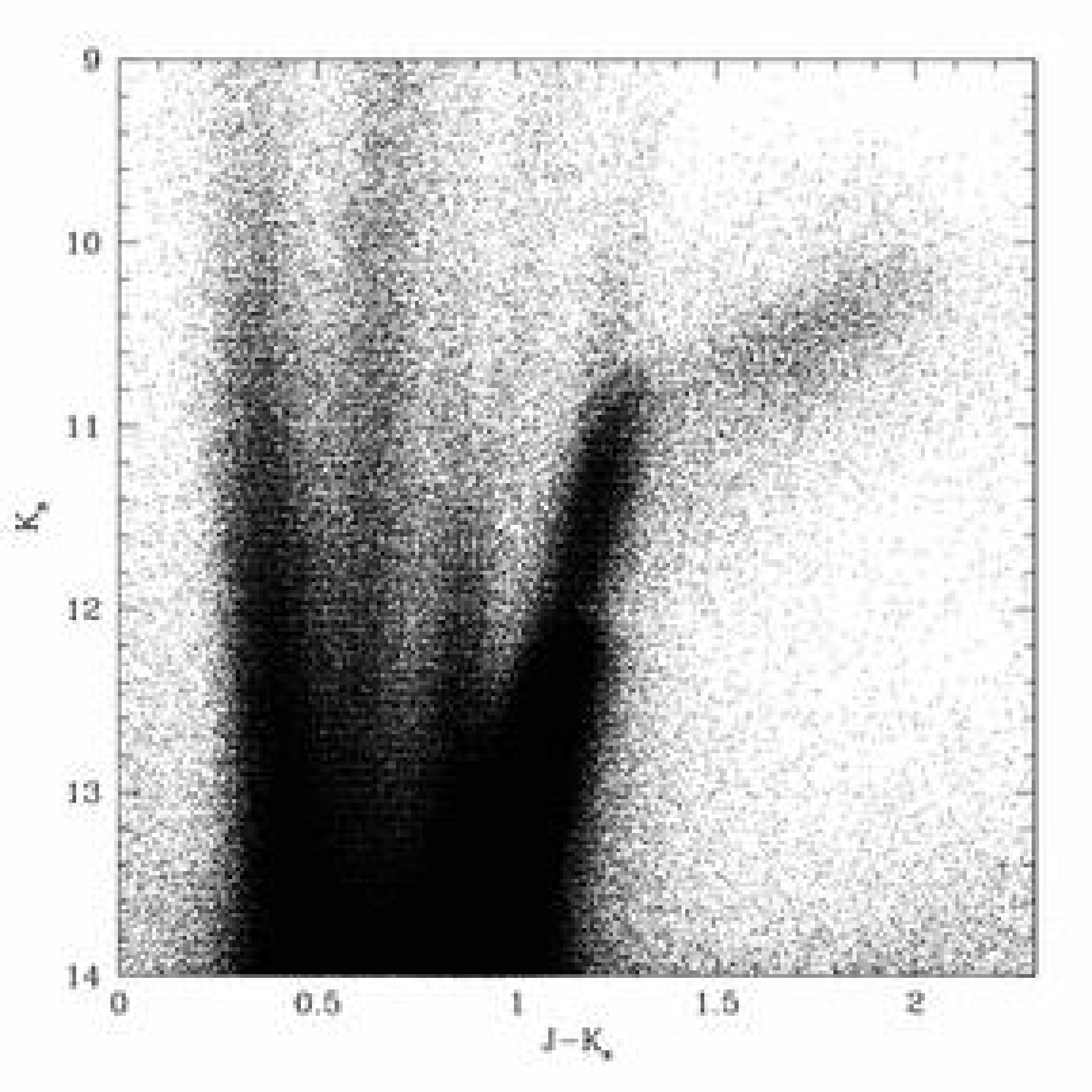
# 2MASS

| | $N_{src}$ | $f_{Gal}$[a] | Region boundaries | Dominant Spectral Types[b] |
|---|---|---|---|---|
| A | 6659 | 0.15 | $11 < K < 14.75$, $J-K < 0.2$ | **B-A I-II, O3-O6 V** |
| B | 77204 | 0.80 | $5.5 < K < 13.5$, $0.2 < J-K < 0.5$ | F-K V |
| C | 62713 | 0.80 | $5 < K < 13.5$, $0.5 < J-K \lesssim 0.8$ | K V, K III |
| D | 440472 | 0.45 | $13.5 < K < 14.75$, $0.2 < J-K < 1.2$ | **K-M III**, F-M V |
| E | 166263 | 0.05 | $12 < K < 13.5$, $0.9 \lesssim J-K \lesssim 1.2$ | **M III, RGB, early-AGB** , M V |
| F | 22134 | 0 | $10.5 \lesssim K < 12$, $1 \lesssim J-K \lesssim 1.3$ | **M, MS** |
| G | 1438 | 0 | $8 < K \lesssim 10.5$, $1.2 \lesssim J-K \lesssim 1.5$ | **M, MS, O-rich LPVs** |
| H | 2450 | 0.05 | $7 < K < 11$, $1 \lesssim J-K \lesssim 1.3$ | **M I-II, RSG** |
| I | 21986 | 0.55 | $11 < K \lesssim 13$, $0.75 < J-K \lesssim 1$ | **K-M I-II**, K-M V, M III |
| J | 8229 | 0 | $9.5 \lesssim K \lesssim 11.5$, $1.4 \lesssim J-K < 2$ | **C III** |
| K | 2212 | 0 | $9 \lesssim K \lesssim 13$, $2 < J-K < 5$ | **C III, dust-enshrouded AGB stars** |
| L | 8940 | 0.01 | $12.5 \lesssim K < 14.75$, $1.2 \lesssim J-K < 2.5$ | M late V |

[a] Fraction of Galactic sources estimated from synthetic W92 model

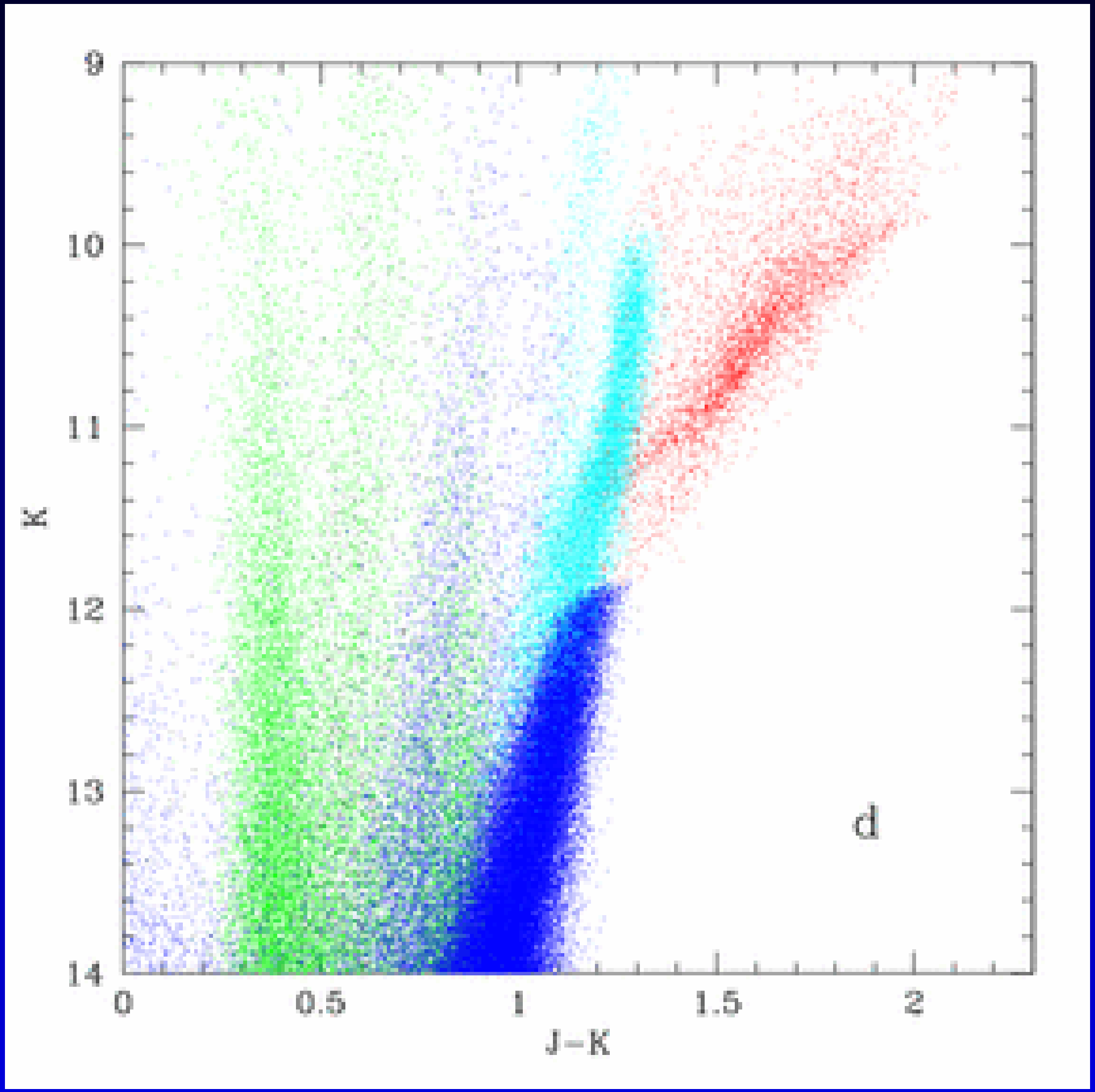
[b] Based on $J - K_s$ color and W92; **LMC** populations in boldface

# 2MASS



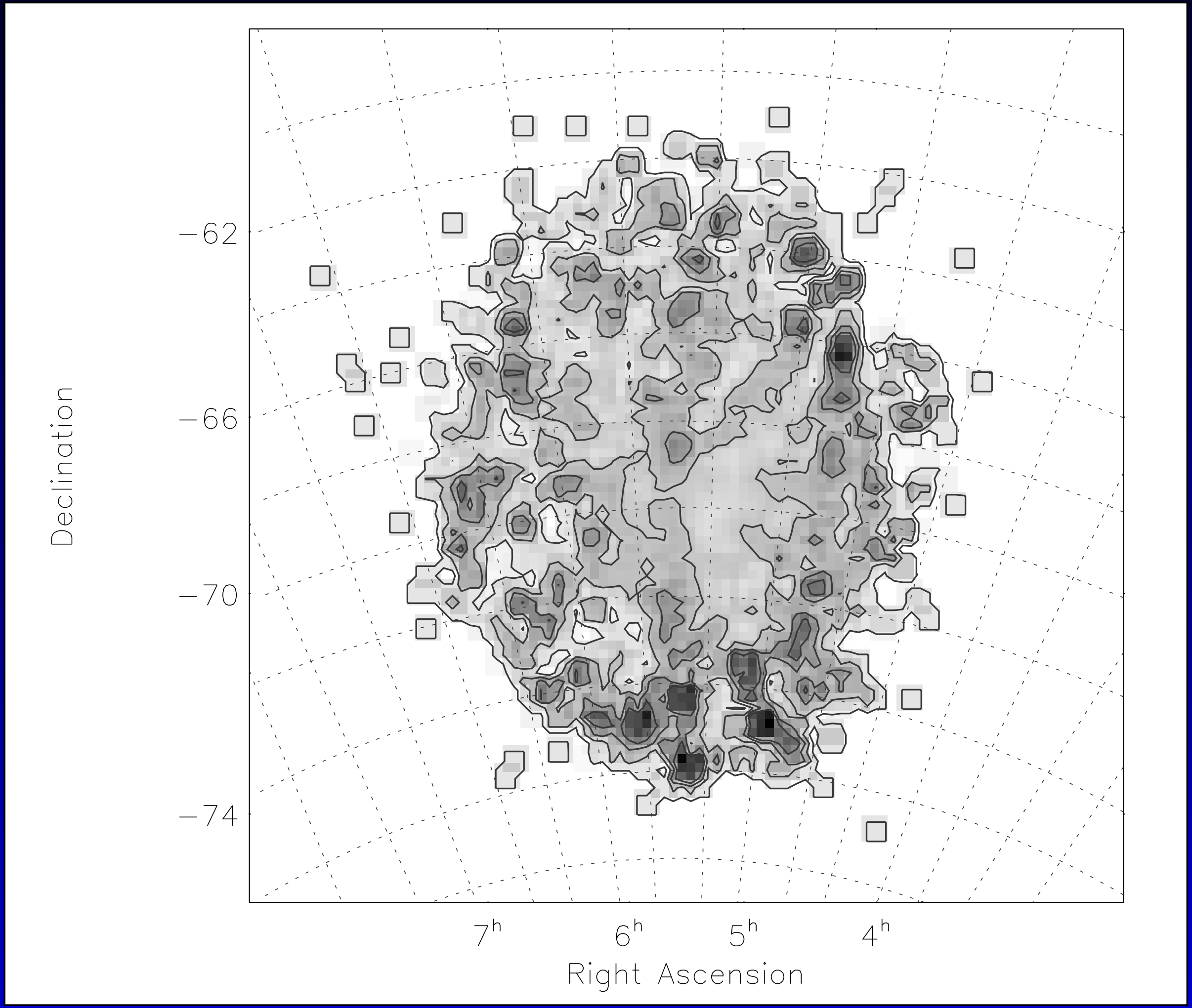

LMC 2MASS Marigo et al. 2003

# 2MASS




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

# 2MASS




LMC C/M0+ ratio based on DENIS.

Cioni & Habing 2003. Metallicity Spread of 0.75 dex.

SMC; NGC 6822 in Cioni & Habing (2005)

# How to identify late-type stars ?

Pulsational variables: Mira / SR / Irr

- Variability

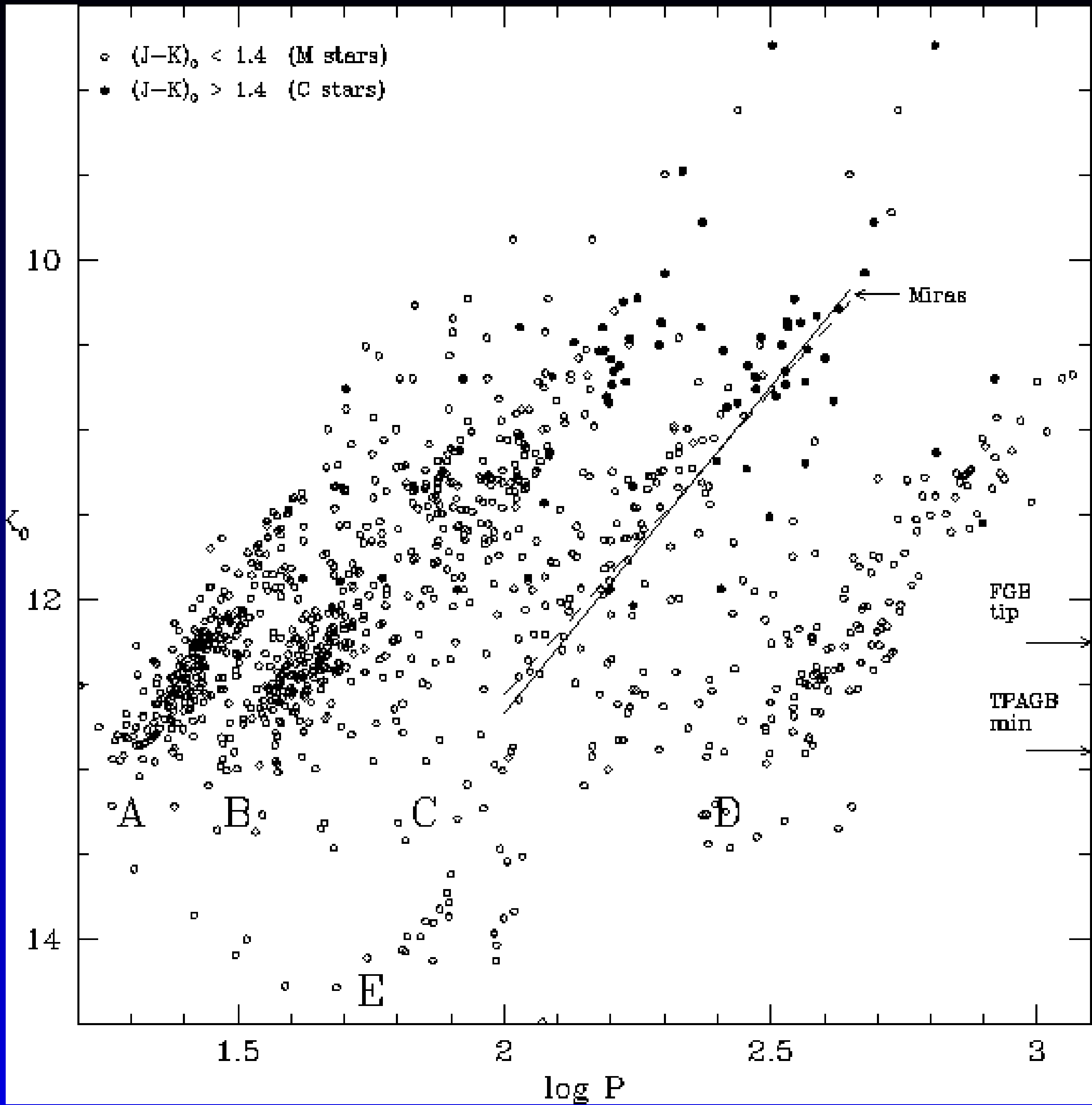
  Disadvantage:
  No M/S/C discrimination
  Observing time demanding

  Advantage:
  $PL$-relation
  Distance estimates

  micro-lensing surveys
  variability surveys

# Miras / LPVs in MCs

- Wood et al. 1999, Wood 2000 (0.25 $\square^2$ LMC-bar; 1430 red variables; MACHO + IR)


(J−K)0 < 1.4 (M stars)
(J−K)0 > 1.4 (C stars)
10
12
14
K0
1.5
2
2.5
3
log P
Miras
FGB tip
TPAGB min
A
B
C
D
E

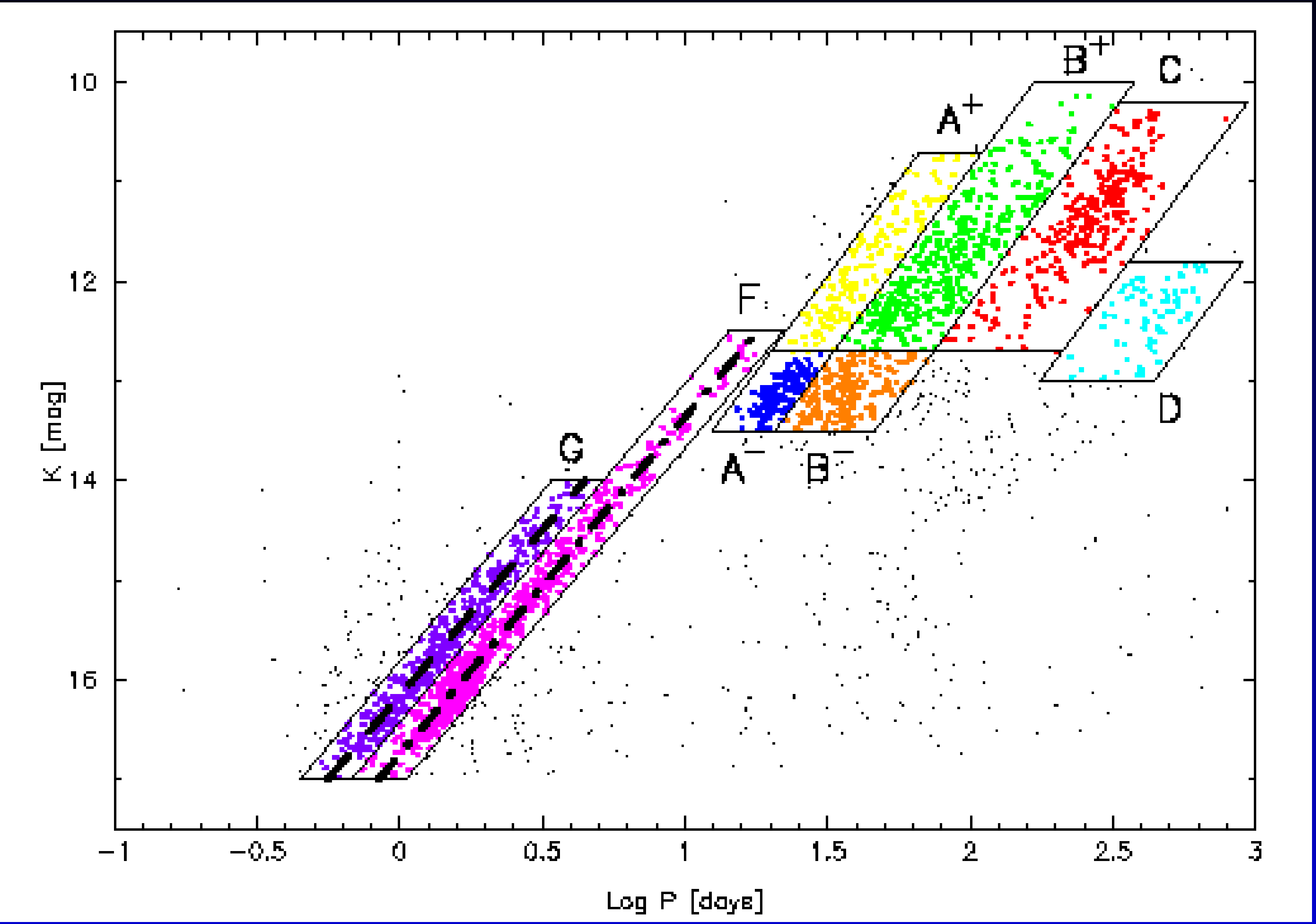
Wood (2000)

# History

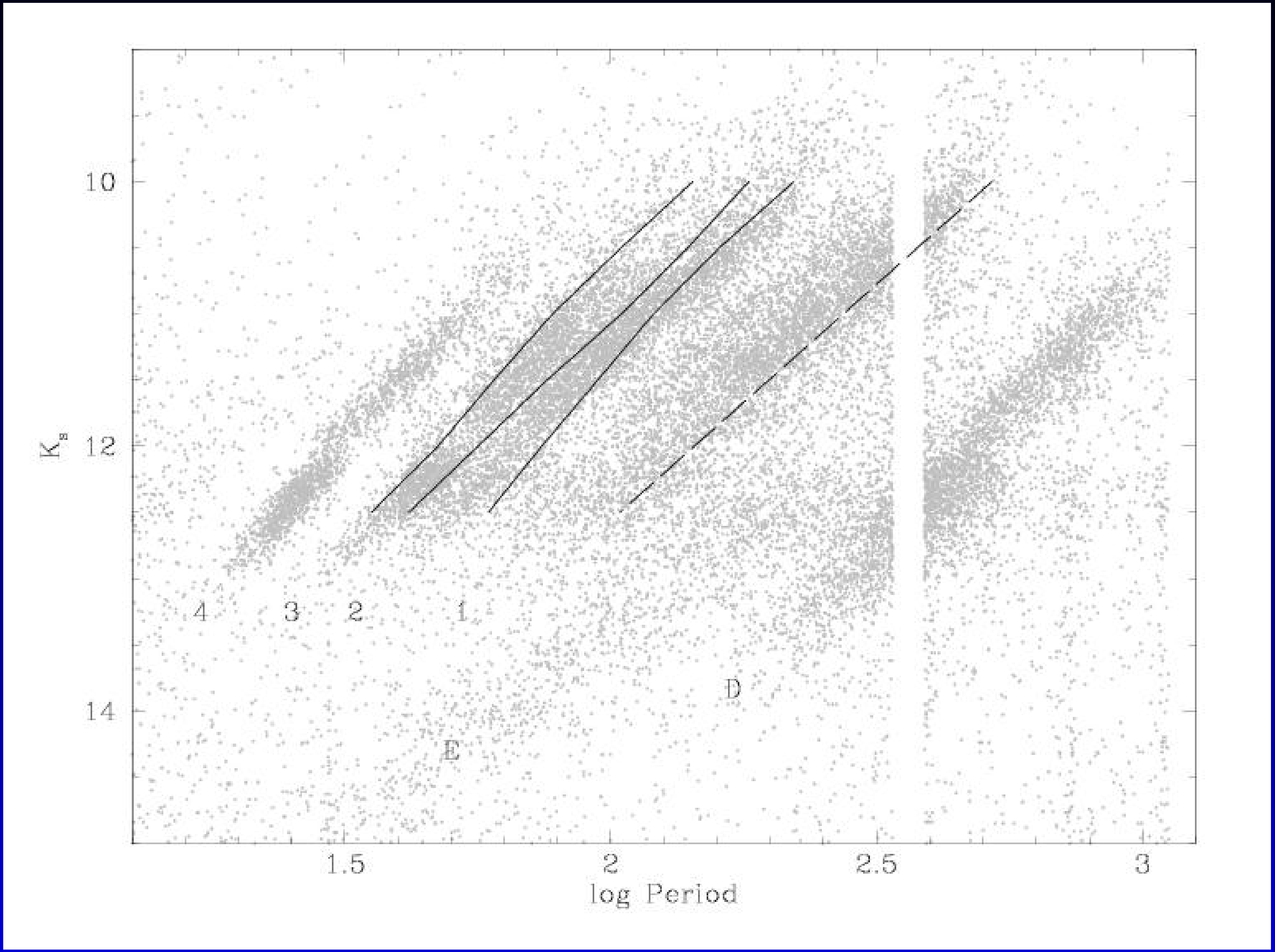
- Wood et al. 1999, Wood 2000
- Cioni et al. 2001
  (0.5 $\square^2$ LMC-OC; 240 M+SR; EROS + DENIS)
- Noda et al. 2002
  (14 $\square^2$ LMC; 146 LPV; MOA + DENIS)
- Lebzelter et al. 2002
  (0.25 $\square^2$ LMC-bar; 470 red variables;
  AGAPEROS + DENIS)
- Cioni et al. 2003
  (0.25 $\square^2$ ISO-sample SMC-bar,
  458 red variables; MACHO + DENIS/2MASS)

# History

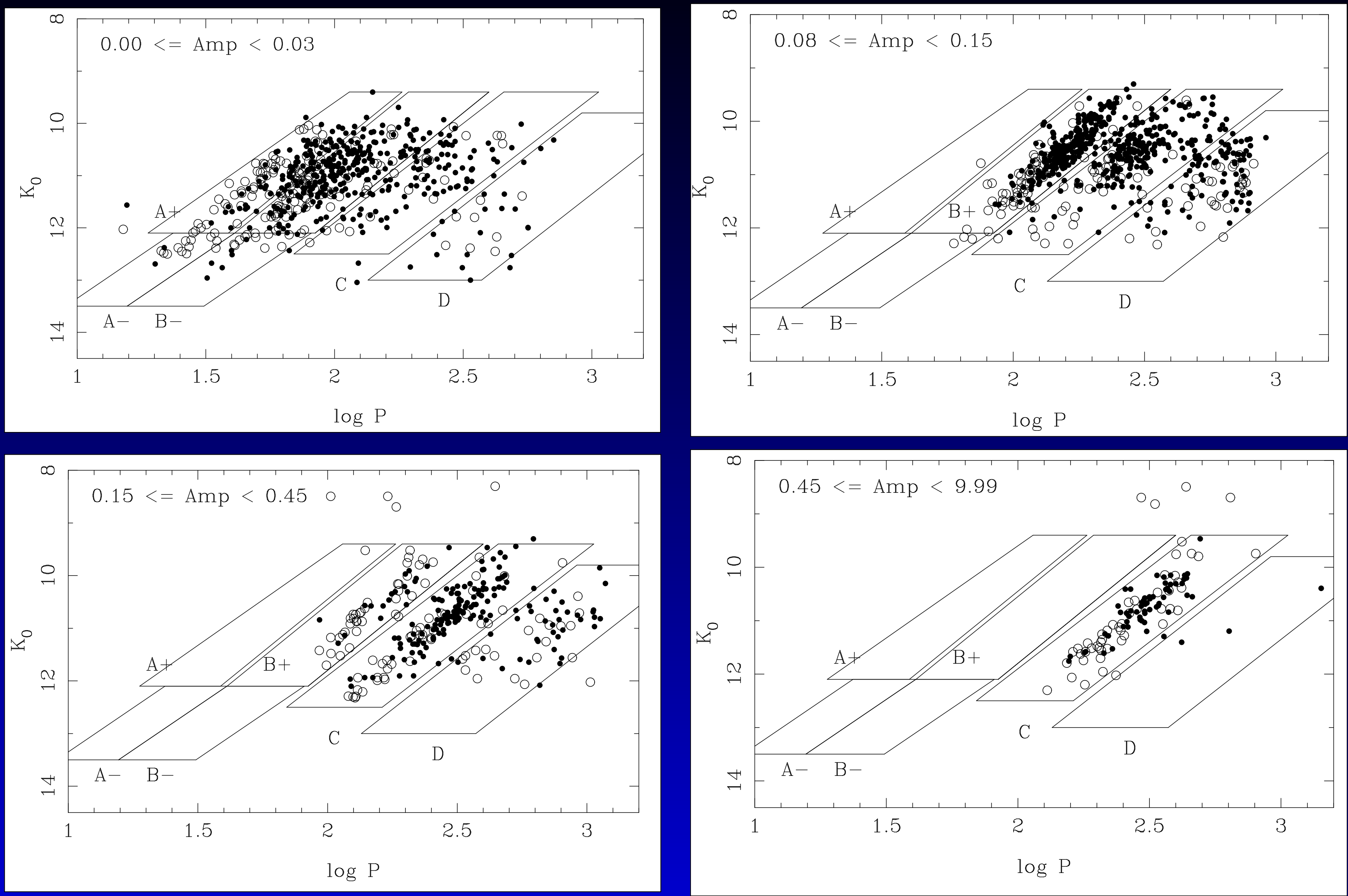
- Ita et al. 2003
  (1.0 $\Box^2$ SMC-centre; $\sim$1800 red variables;
  OGLE + SIRIUS)
- Kiss & Bedding 2003
  ($\sim$23 000 red variables LMC;
  OGLE + 2MASS with $J - K > 0.9$)
- Groenewegen (2004)
  SMC+LMC; OGLE + 2MASS/DENIS
  (2277 spectroscopically confirmed M,S,C-stars)
- Fraser et al. (2005)
  (22 000 LMC MACHO + 2MASS)
- Raimondo et al. (2005)
  (1000 known C-stars in SMC; MACHO +
  2MASS/DENIS)




Ita et al. (2003)




Fraser et al. 2005




LMC LPVs from Groenewegen (2004)

$PL(K)$-relation for different cuts in amplitudes

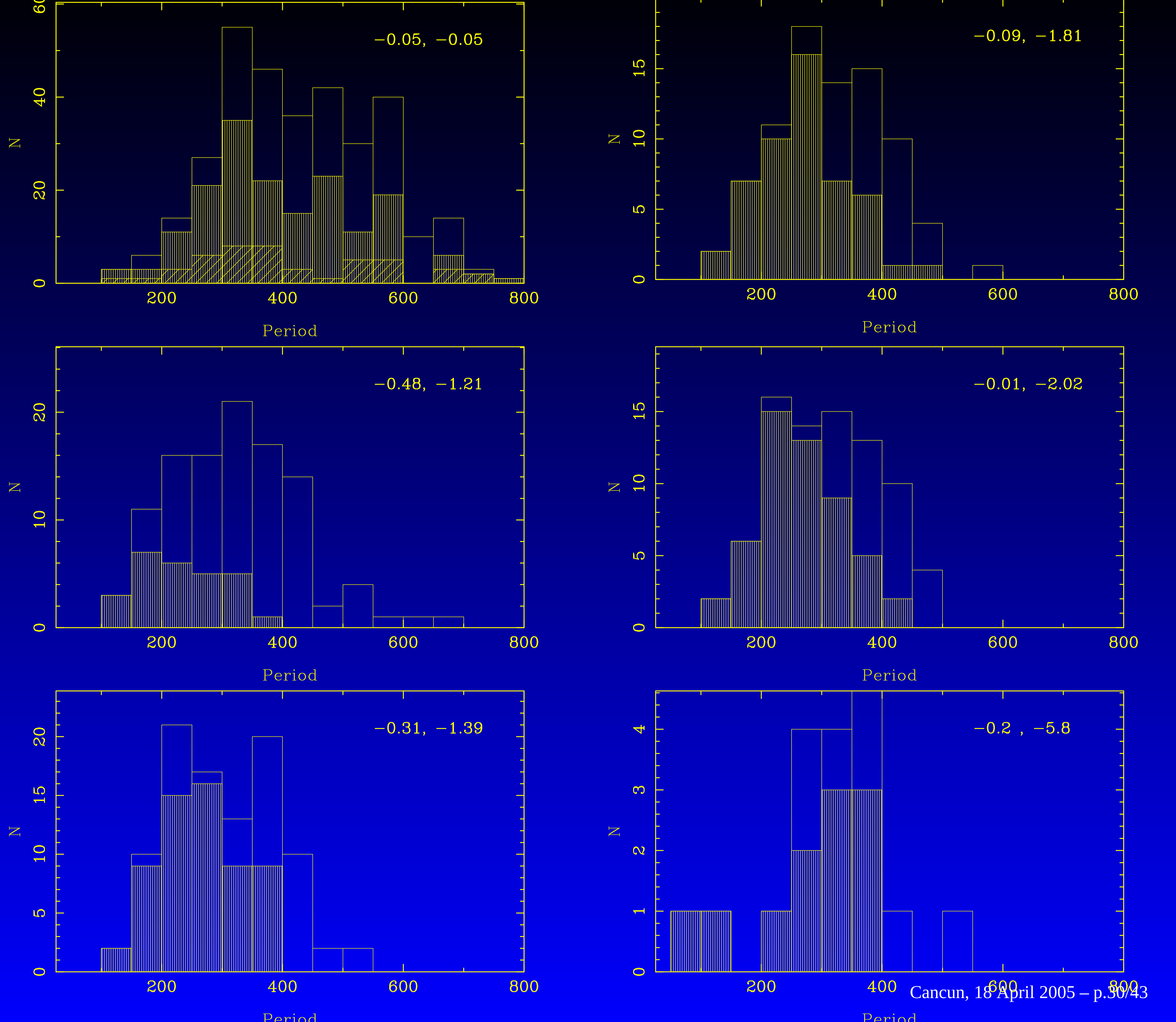
Known C/M-stars in filled/open symbols

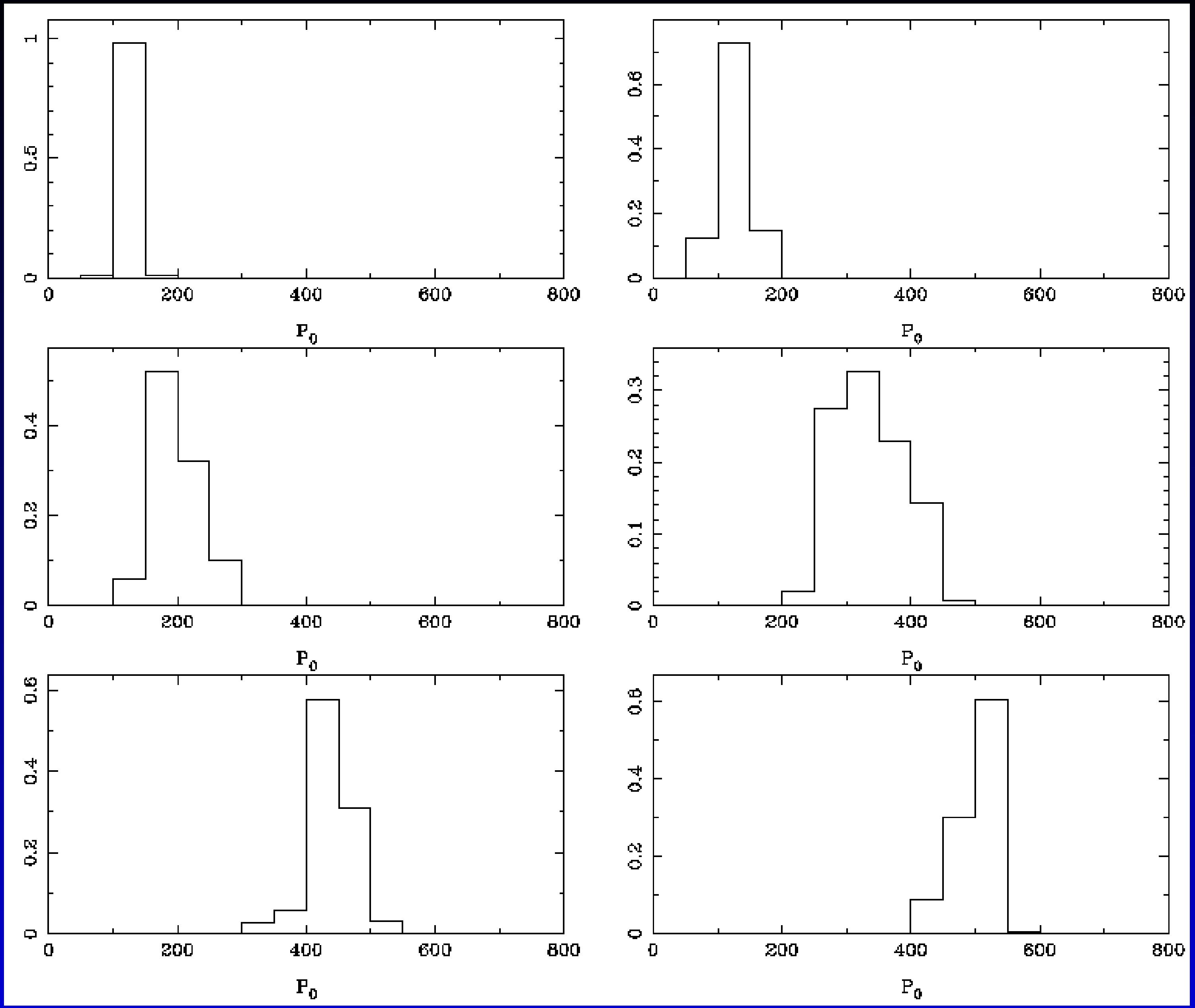
# LPVs in the Galactic Bulge

- Alard et al. (2001)
  MACHO, 332 ISOGAL sources in NGC 6522 and Sgr I Baades windows ($V$, $R$ and [7],[15])
- Schultheis & Glass (2001)
  extended Alard et al. by DENIS and 2MASS.
- Glass & Schultheis (2002)
  174 M-giants in NGC 6522 Baades window; MACHO; DENIS + ISOGAL
- Glass & Schultheis (2003)
  MACHO, NGC 6522 Baades window, DENIS. 1085 of 1661 stars are variable.
- Wray et al. (2004) 13 000 small amplitude red giants variables in a sub-set of 33 OGLE fields.
- Groenewegen & Blommaert (2005)

# LPVs in the Galactic Bulge

- Groenewegen & Blommaert (2005)
- 2691 Miras in 49 OGLE fields:
  $m_{\rm K} = (-3.37 \pm 0.09) \log P + (15.47 \pm 0.03)$
- Viewing angle of the Bar: $43 \pm 17$ degrees
- Distance GC: 8.6 - 9.0 kpc
- Period distribution at various $b$ indicate differences in population


−0.05, −0.05
−0.09, −1.81
−0.48, −1.21
−0.01, −2.02
−0.31, −1.39
−0.2 , −5.8
N
Period




Theoretical period distribution of optically visible stars inside the observed instability strip for masses 1.1, 1.2, 1.5, 2.0 (1.2 Gyr), 2.5, 3.0$M_\odot$ (200 Myr) (left to right, top to bottom)

# Red variables in the Galaxy

- GCVS
- AAVSO, AFOEV
- ASAS (All Sky Automated Survey)
  http://sirius.astrouw.edu.pl/~gp/asas/
  $\delta < +28^o$, 3 years, $V = 5 - 14$, 15 $10^6$ stars
  40 000 variables; 2500 Miras
- NSVS (Northern Sky Variability Survey)
  http://skydot.lanl.gov/
  $\delta > -38^o$, 1 yr, $V$ = 10-15.5, $10^7$ stars

  Wozniak et al. (2004): 8600 evolved stars

# How to identify late-type stars ?

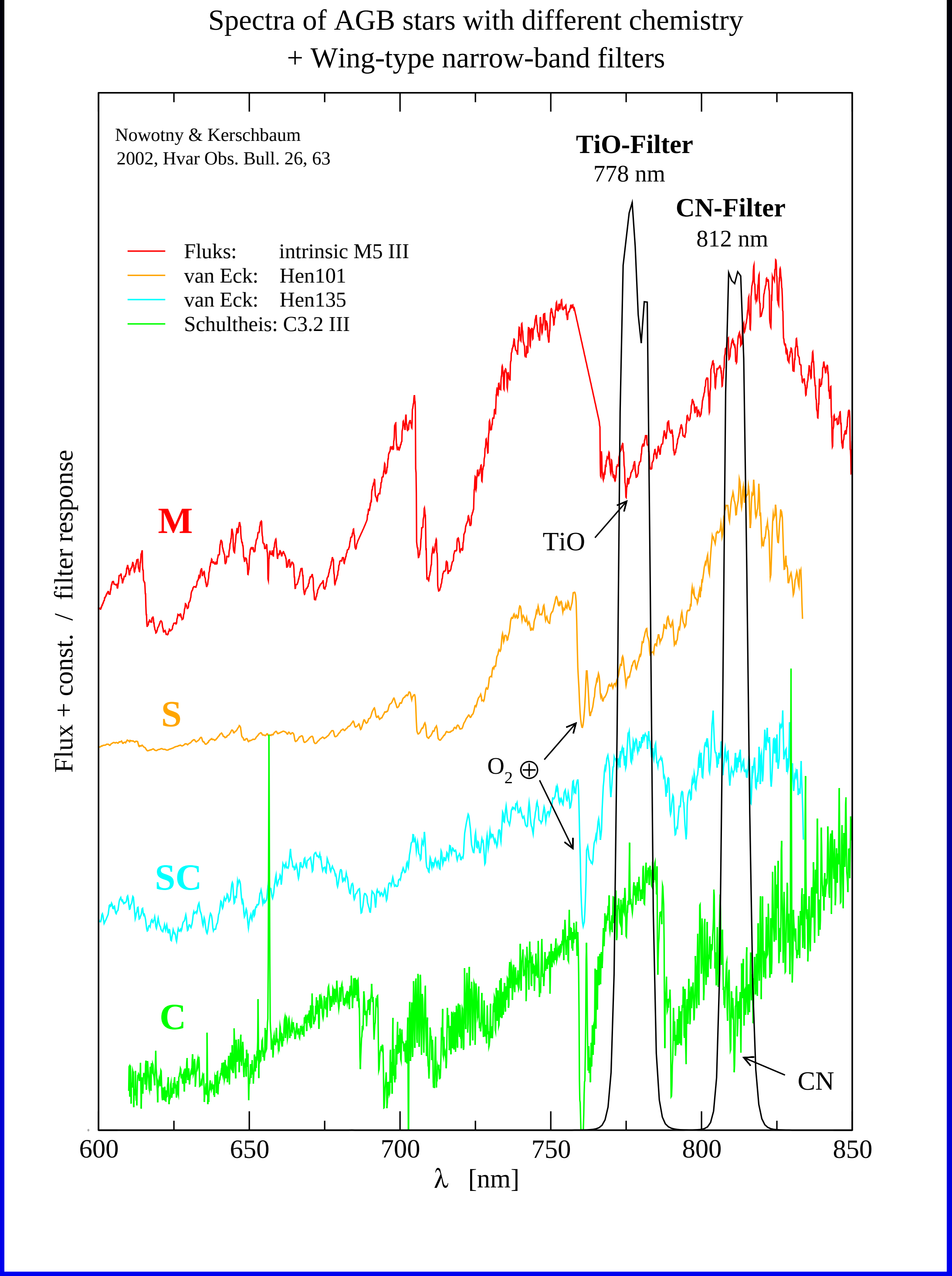
Chemical peculiarities

- Narrow-band filters

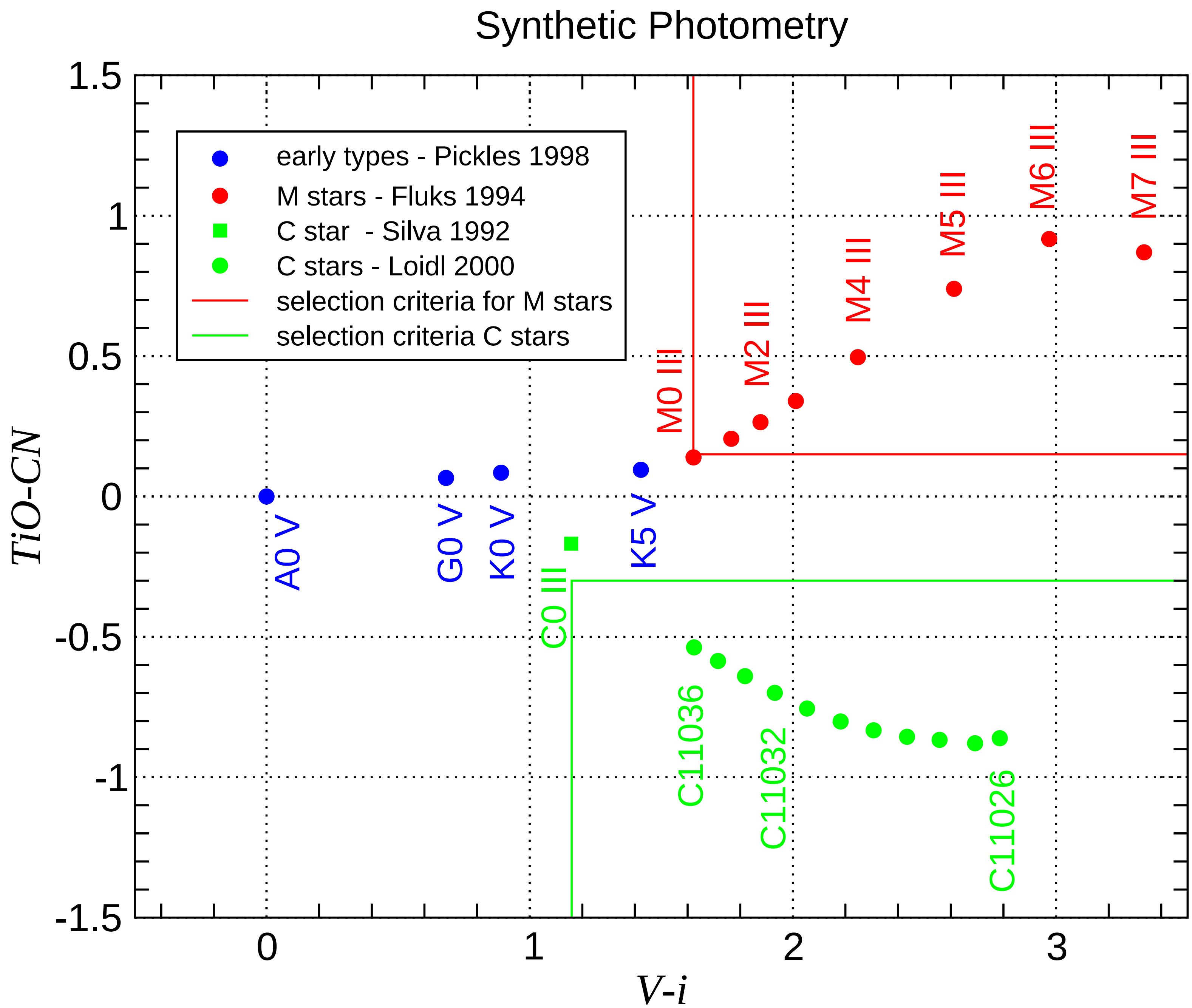
  Richer et al. (1984); Aaronson et al. (1984)
  broad-band $V$,$R$,$I$ + narrow-band 7800, 8100

  advantage: spectroscopic identification
  disadvantage: foreground M-stars

  specific surveys




# Nowotny & Kerschbaum 2002




Nowotny & Kerschbaum 2002

# Recent narrow-band surveys

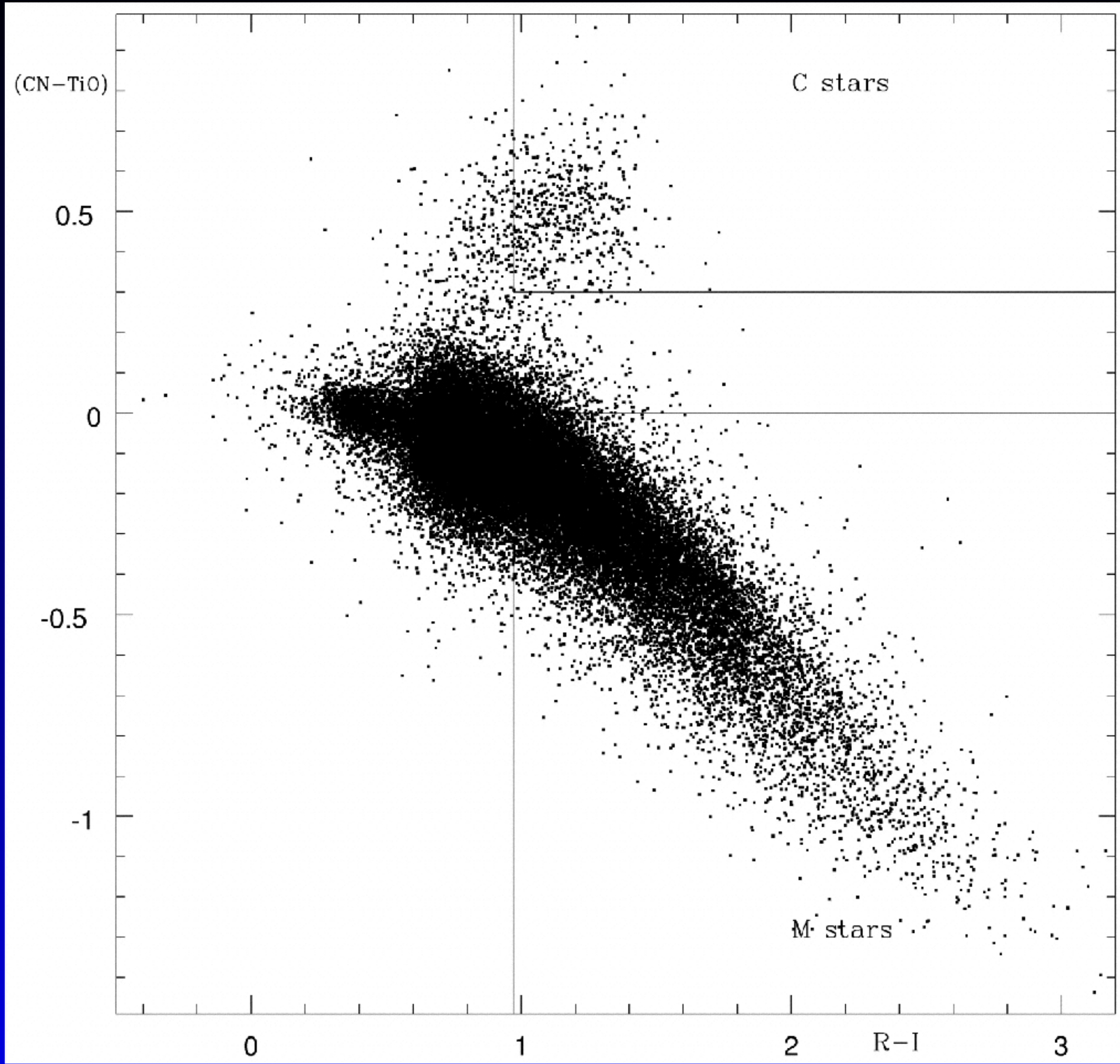
- Battinelli/Demers/LeTarte:

  NGC 205 (525), NGC 3109 (446), WLM (149)
  NGC 147 (288), NGC 185 (145), IC10 (676)

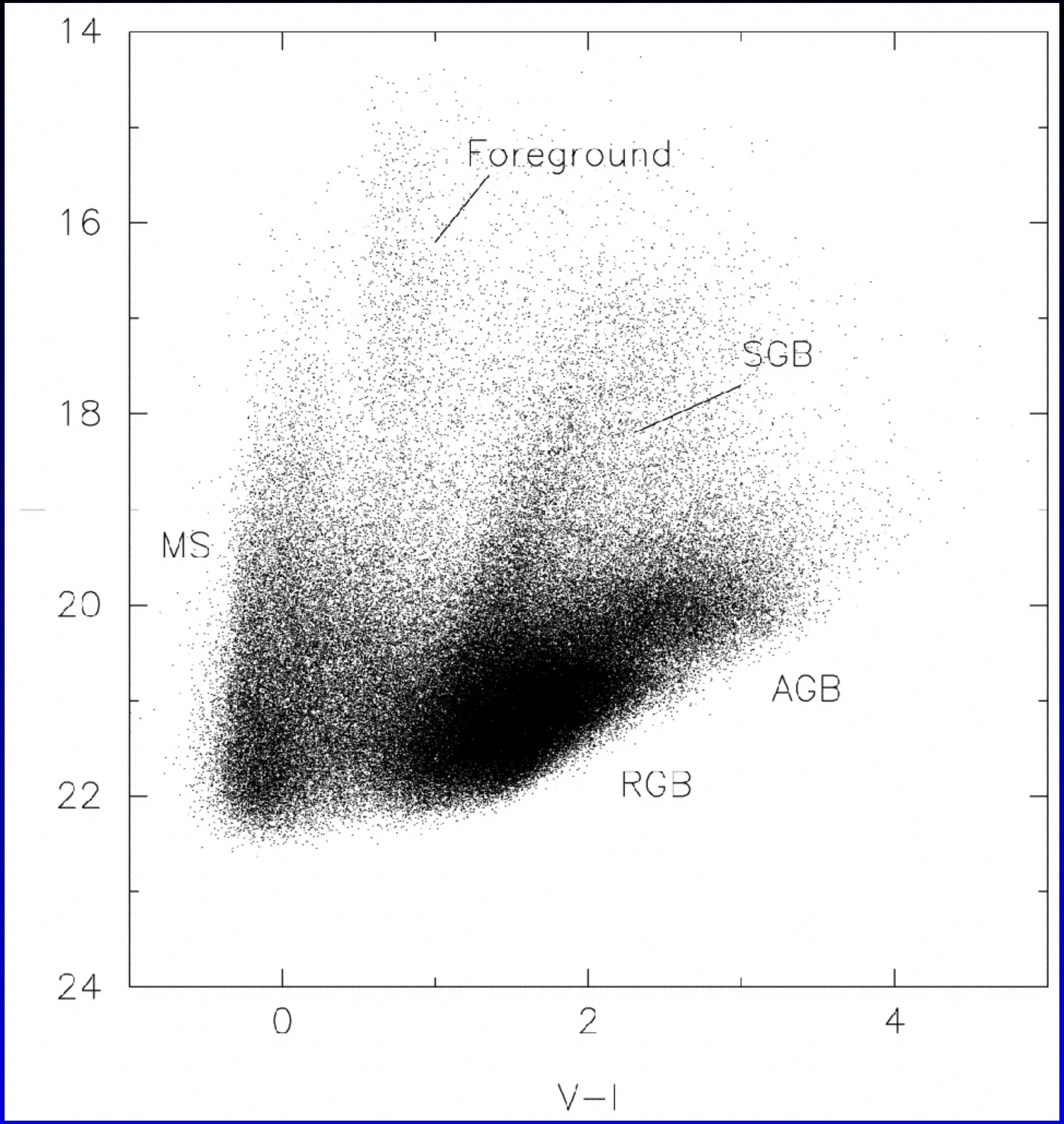
- Nowotny et al. (2003): NGC 147 (146),
  NGC 185 (154)
  Kerschbaum et al. (2004): And II (7)

- Harbeck et al. (2004): NGC 147 (155),
  Cetus DSph (1), And III (0), V (0), VI (1), VII (3)
  Harbeck et al. (2005): And IX (1?)

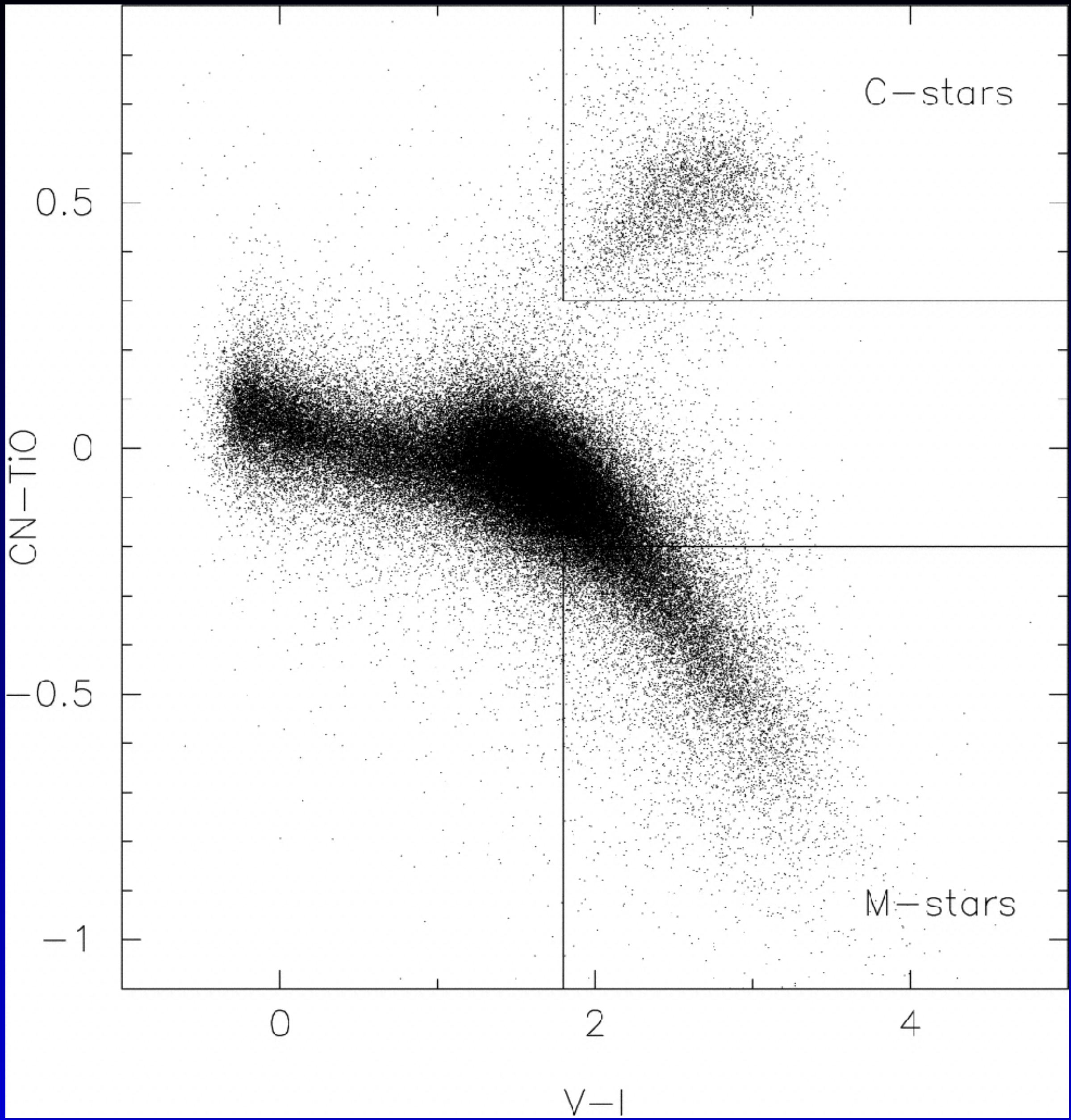
- Rowe et al. (2005): M33 (7900)




Demers et al. (2003) for NGC 205




Rowe et al. (2005) for M33




Rowe et al. (2005) for M33

# Theory

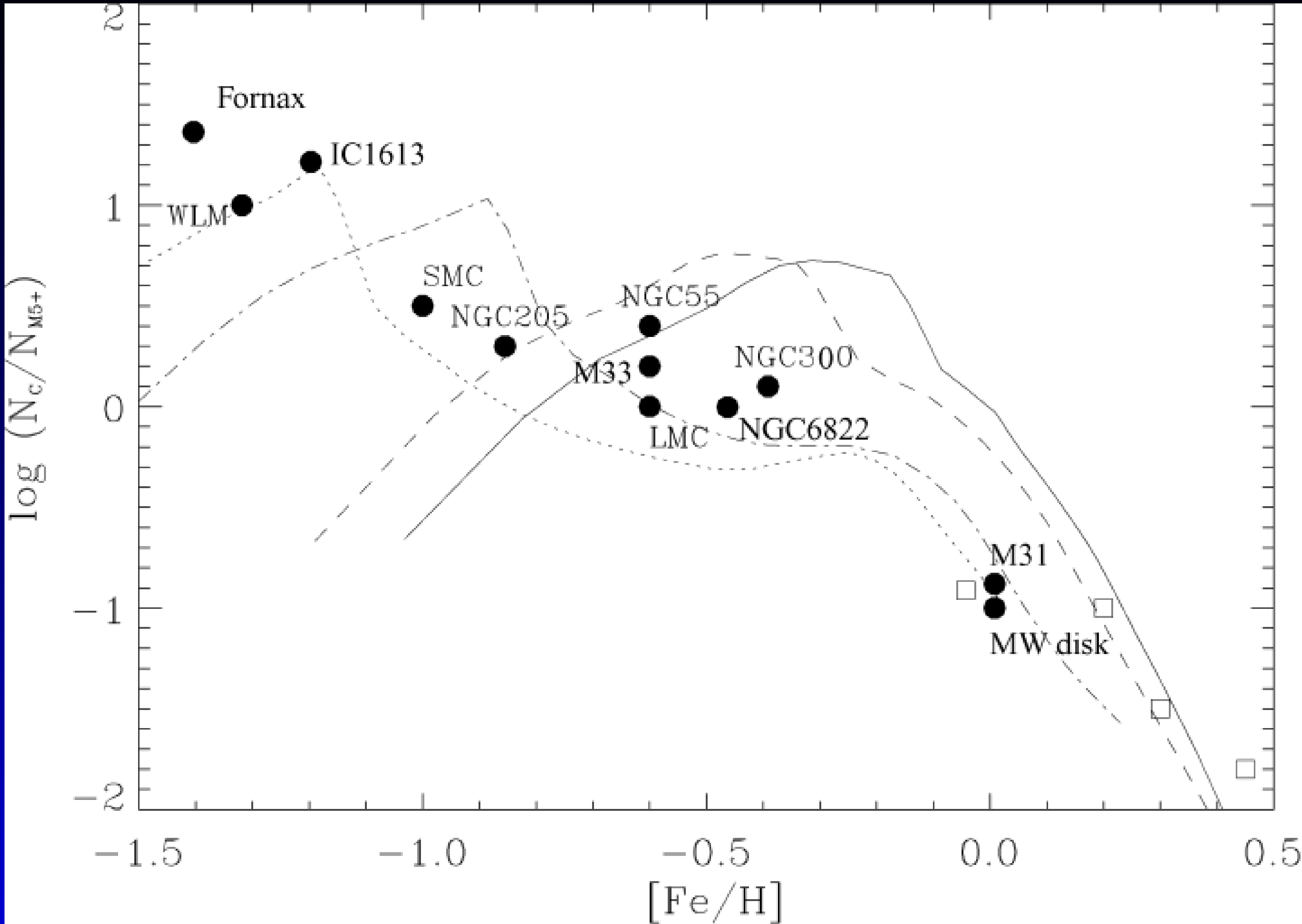
- Mouhcine & Lançon (2003)

  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 survey very powerfull
  Quantitative theoretical interpretation is lacking

  -Dredge-up as a function of metallicity
  -Mass-loss as a function of metallicity

- Micro-lensing surveys have had a huge impact on variable star research

  ASAS/NSVS could give complete picture of solar neighbourhood

- 2MASS:
  - Galactic/ MC Structure
  - IR photometry for Miras (Cepheids)

THE END