Luminosities and mass-loss rates of AGB Stars in the MCs

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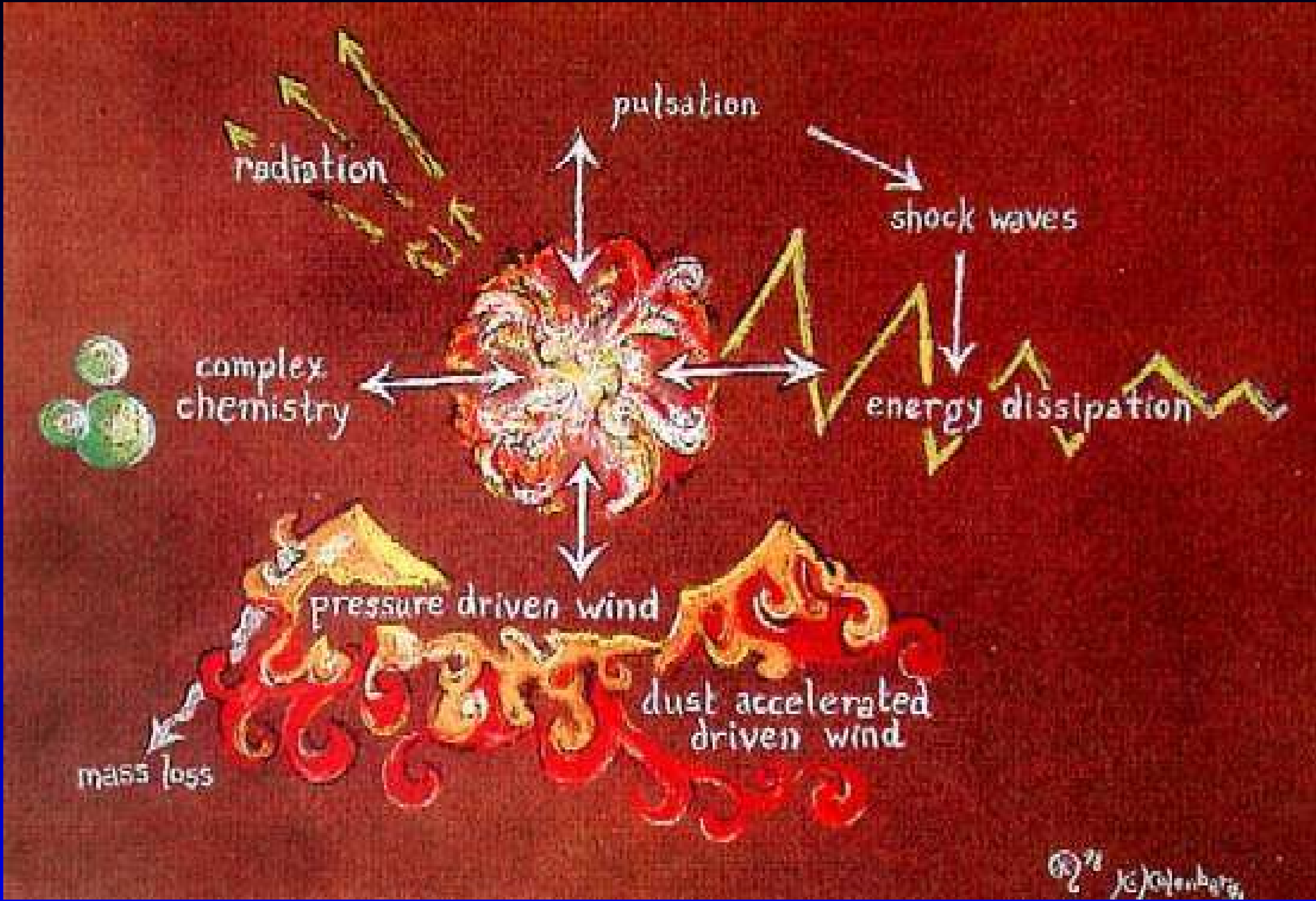
Overview Talk

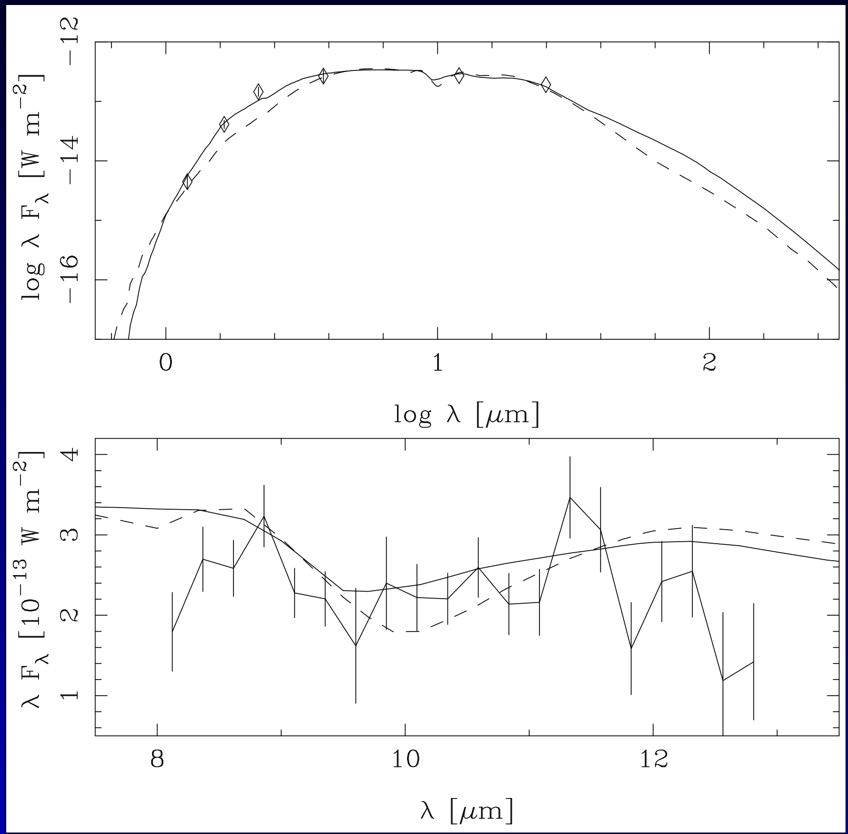
- Introduction
- Sample (AGB & RSG with *Spitzer* IRS in MCs)
- Results
- Prospects

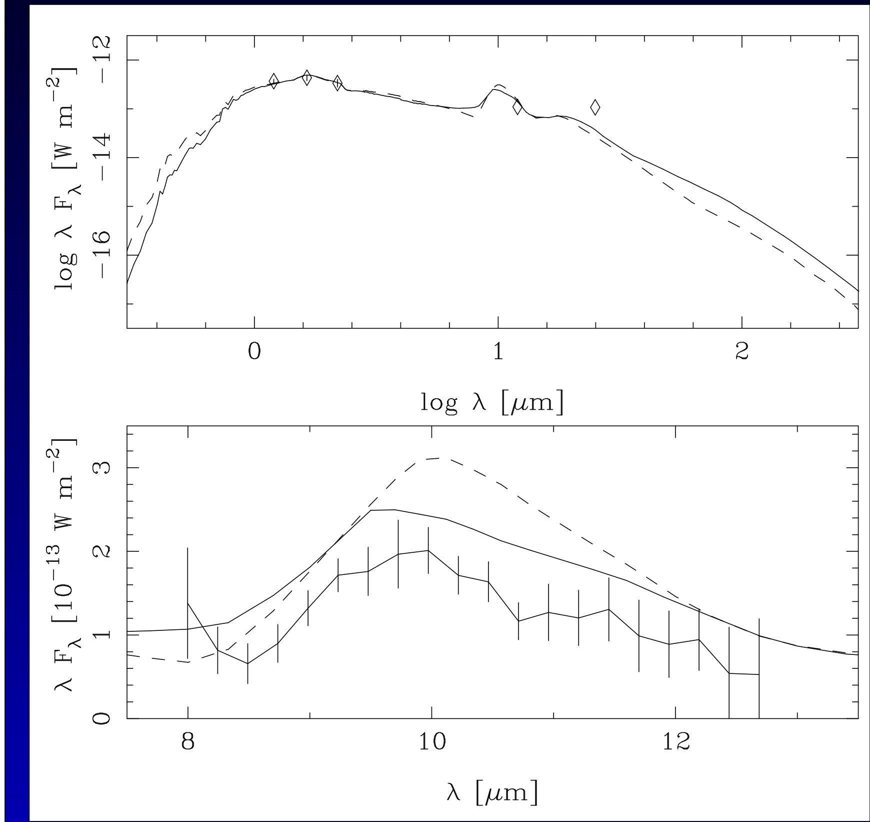


radiation
pulsation
shock waves
complex chemistry
energy dissipation
pressure driven wind
dust accelerated driven wind
mass loss

Introduction

- IRAS, at the limit at 12 and 25 micron
  Reid (1990, 1991), Wood (1992), Zijlstra (1996)
  Groenewegen & Blommaert (1998) (SMC)
  Groenewegen et al. (1995) mid-IR spectra
- ISO
  Trams et al. (1999)
  ISOCAM, ISOPHOT photometry and spectroscopy of 57 sources
- Spitzer
  Photometry and spectroscopy
- Herschel
  Usefull in individual cases





LMC source TRM60, and SMC source GM 103
Groenewegen et al. (1995)

Determining (Dust) MLR

Fitting SEDs (typically photometry)

- SAGE approach: Fit pre-computed model grid
  Riebel et al. (2012)
- Alternative: model individual SEDs

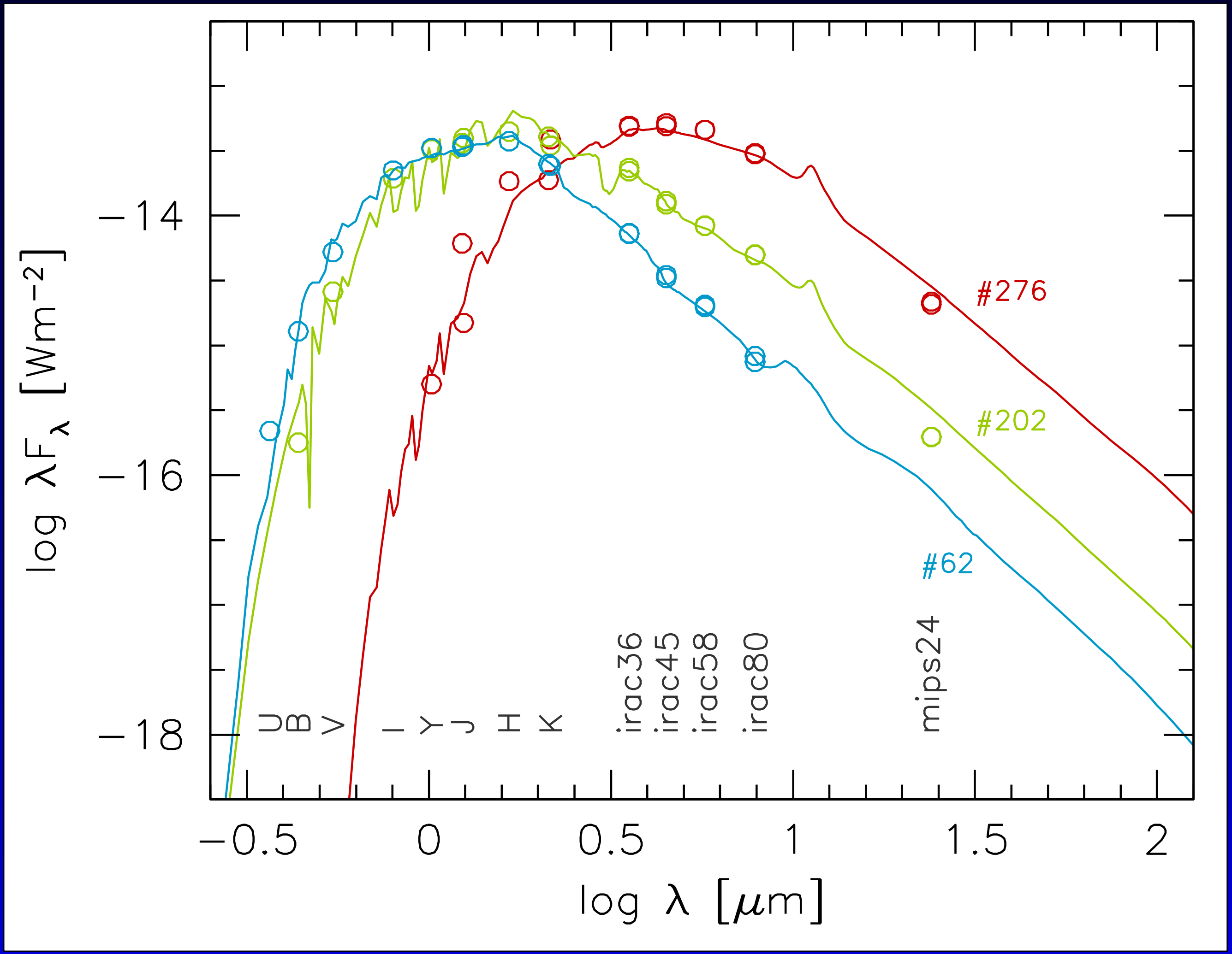
  (Gullieuszik et al. 2012, "The VMC survey III")
  VMC YJK

Issues:
O-rich or C-rich ?
variability
how to weigh photometry versus spectroscopy in the minimization

Gullieuszik et al.

- selected 367 AGB star (candidates) in one VMC tile (1.5 deg^2), based on $(K, J-K)$, and ([8.0],[4.5-8.0]) CMD
- Collected photometry, and SEDs fitted (example)
- Luminosity, and MLR, and chemical type
- Chemical classification tested:
  - Known C-stars in the field (Kontizas et al.) 76/87 (=87%); $(J-K) > 1.5$ even 54/54
  - IRS Spectroscopic sample (fitting only the photometry!) C-stars: 95%; O-stars: 75% correct

Gullieuszik et al.



blue: O-rich with $J - K \sim 1.2$,
green: C-rich $J - K \sim 1.5$, red: C-rich $J - K \sim 4$

Gullieuszik et al.

C-rich

$\dot{M}$ range $M_\odot$ yr^{-1}	$N_{\rm M09}$	N	$\dot{M}_{\rm TOT}$ $10^{-5} M_\odot$ yr^{-1}
$< 1 \times 10^{-6}$	9.1	102	1.5
$1 \times 10^{-6} < \dot{M} < 3 \times 10^{-6}$	8.1	6	1.1
$3 \times 10^{-6} < \dot{M} < 6 \times 10^{-6}$	4.4	3	1.3
$6 \times 10^{-6} < \dot{M} < 1 \times 10^{-5}$	1.8	0	0
$1 \times 10^{-5} < \dot{M} < 3 \times 10^{-5}$	1.8	2	2.5
$3 \times 10^{-5} < \dot{M} < 6 \times 10^{-5}$	0.5	0	0
$> 6 \times 10^{-5}$	0.2	0	0
Total:			6.4

O-rich

$\dot{M}$ range	$N_{\rm M09}$	N	$\dot{M}_{\rm TOT}$
$< 1 \times 10^{-6}$	-	65	0.05
Total:			0.05

Spitzer IRS program

200 (P.I. J. Houck)
3277 (P.I. M. Egan)
3426 (P.I. J. Kastner)
3505 (P.I. P. Wood)
3591 (P.I. F. Kemper)
30788 (P.I. R. Sahai)
40159 (P.I. X. Tielens)
40650 (P.I. L. Looney)
50167 (P.I. G. Clayton)
50240 (P.I. G. Sloan)

SED fitting in MCs

Update of:
Groenewegen M.A.T., Sloan G.C., Soszynski I., Petersen E.A. 2009, A&A 506, 1277

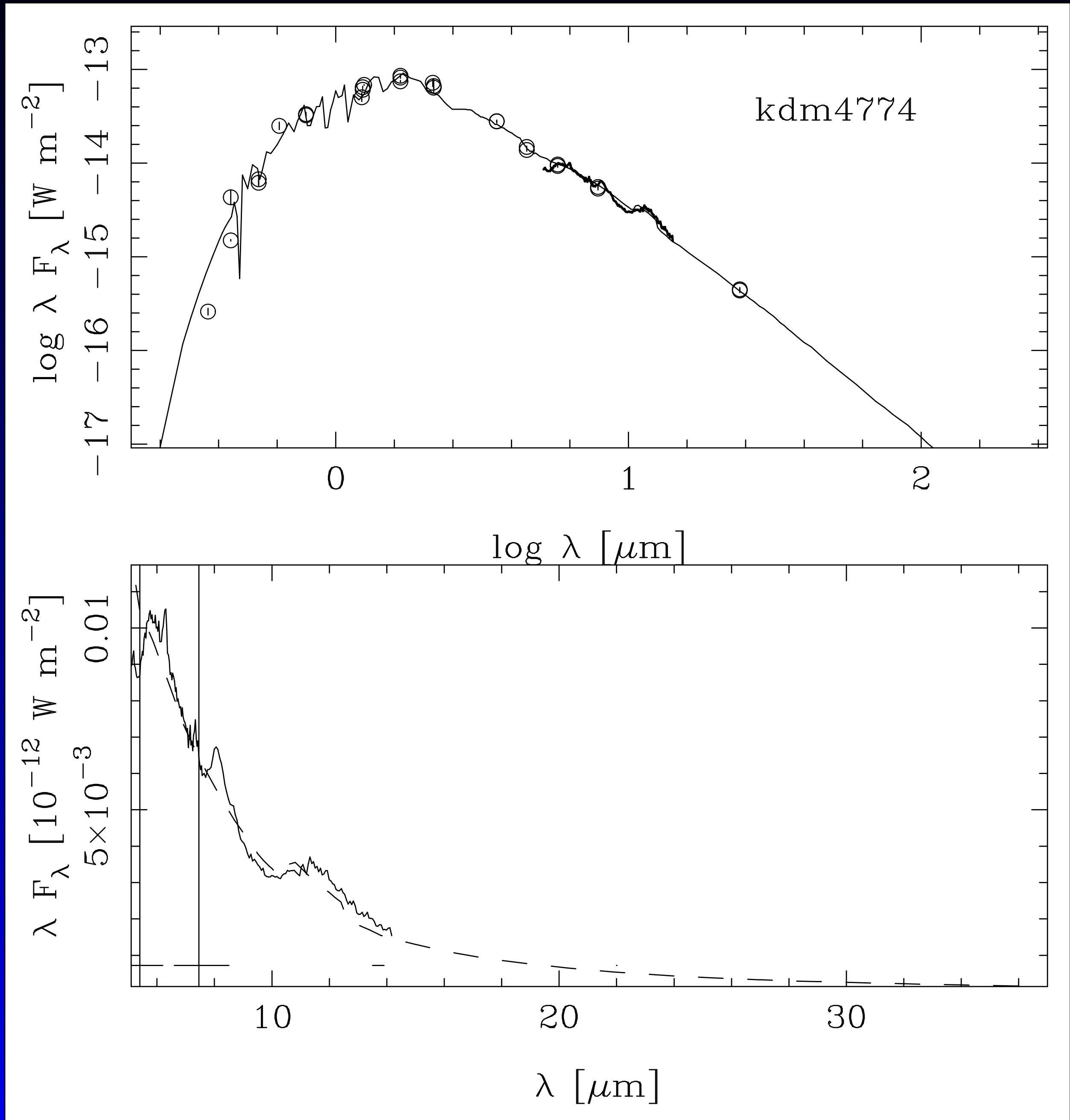
SED fitting of 101 C- and 86 O-rich stars in MCs with IRS spectra

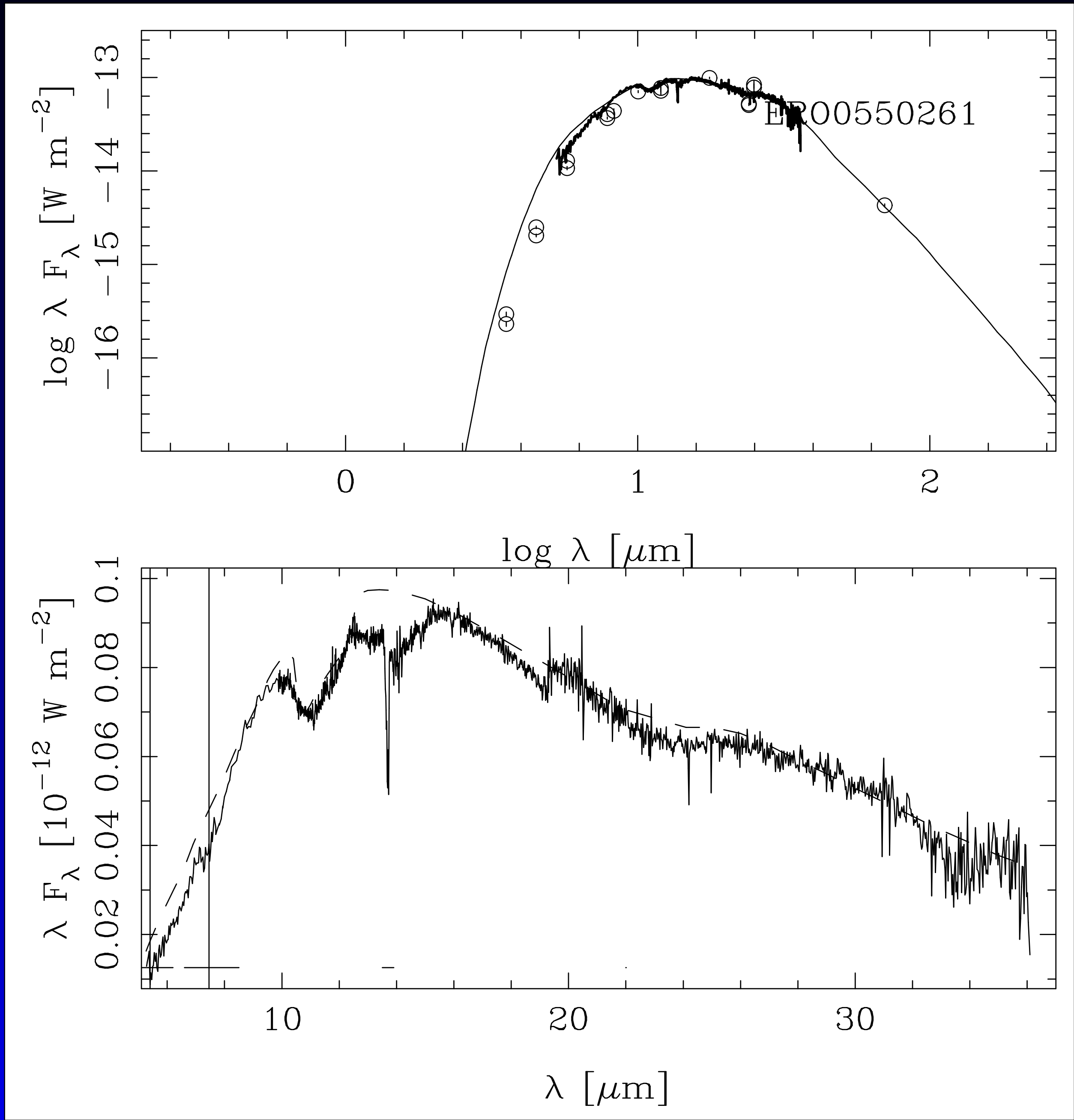
Presently:
191 (43 SMC) C- and
166 (38 SMC) O-rich stars
(11 FG, 78 RSG, 77 O-AGB)

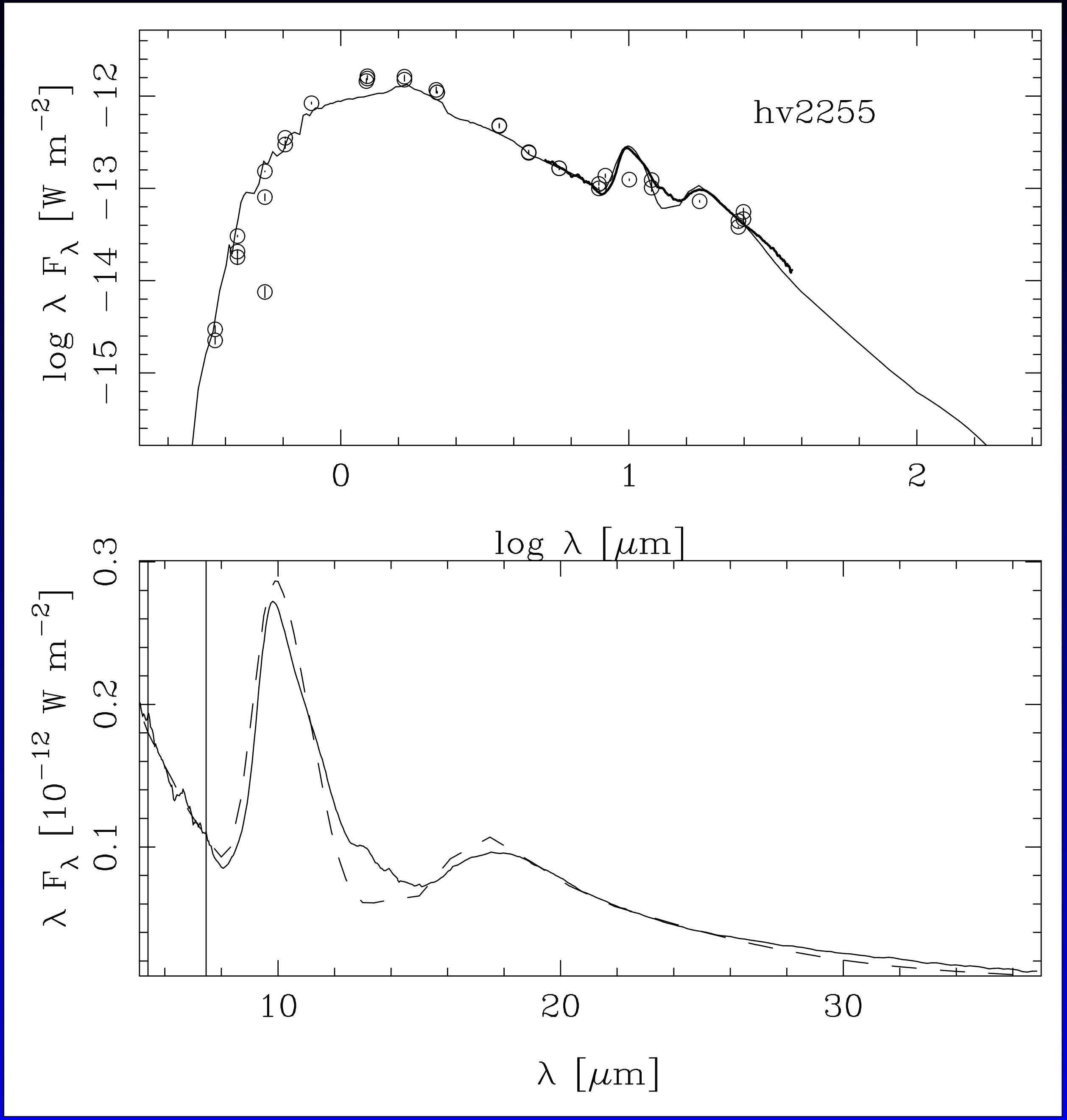
SED fitting

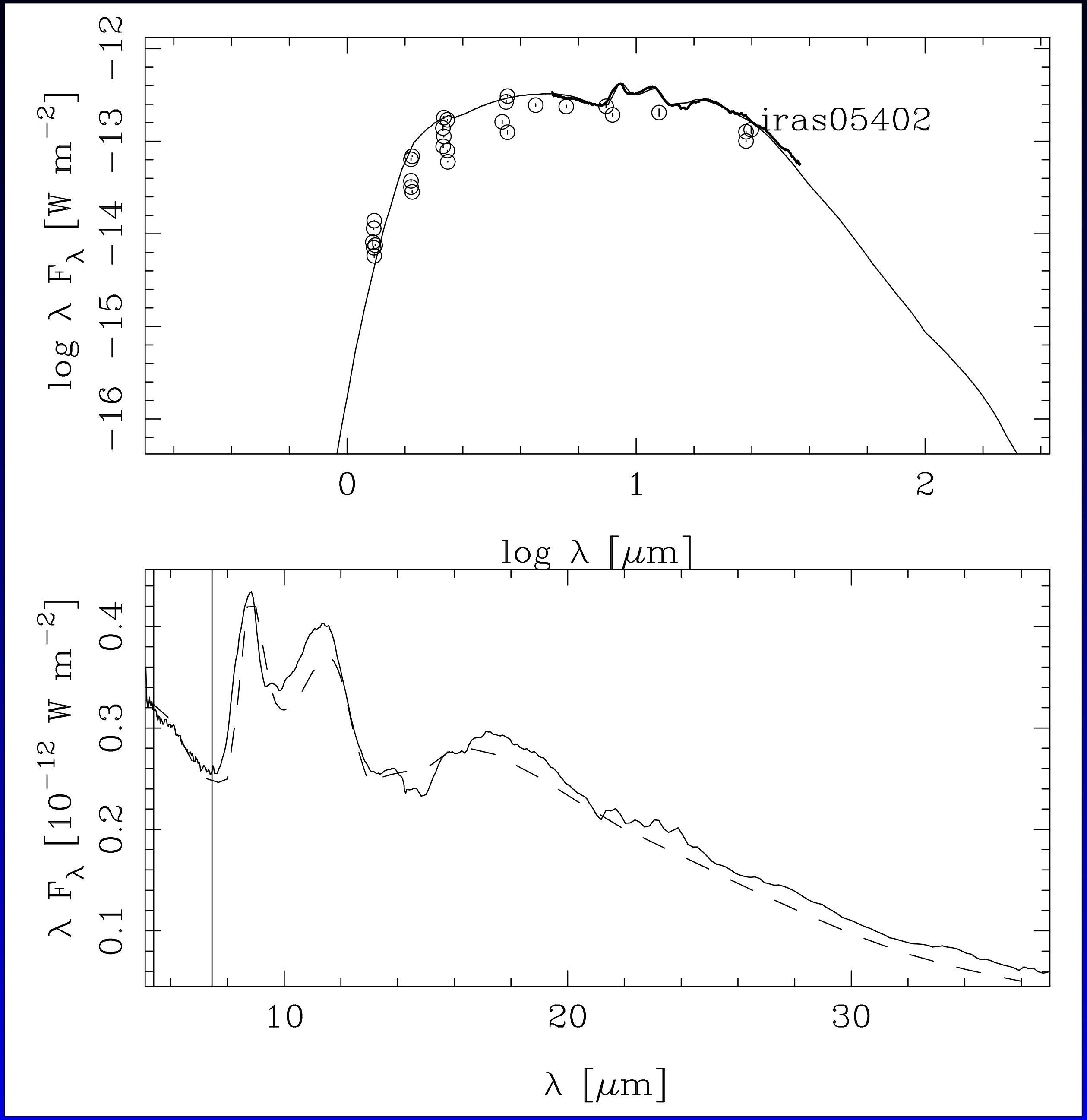
- "More of DUSTY" (Groenewegen 2012)
  DUSTY as subroutine in minimalisation routine
  $\Rightarrow$ fits L, τ
- Improved stellar model atmospheres:
  MARCS (M), Aringer et al. (C)
- Photometry (SAGE, WISE, Akari)

- Dust properties from optical constants
- Assumptions:
  Dust-to-gas ratio of 0.005
  Dust expansion velocity of 10 km/s

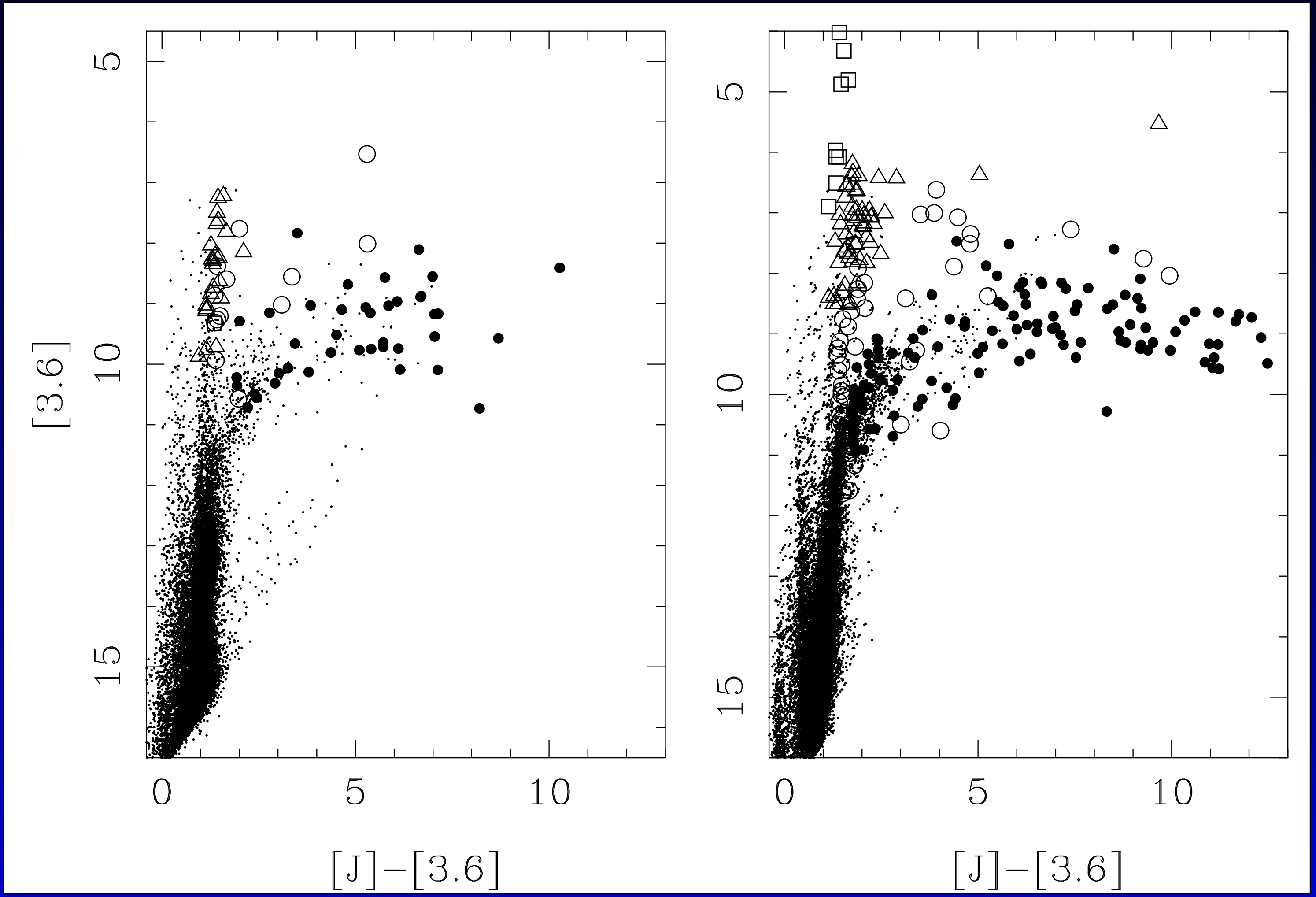

kdm4774
log λ F_λ [W m^−2]
−17
−16
−15
−14
−13
0
1
2
log λ [μm]
λ F_λ [10^−12 W m^−2]
5×10^−3
0.01
10
20
30
λ [μm]


ERO0550261
log λ F_λ [W m^-2]
-16 -15 -14 -13
0 1 2
log λ [μm]
λ F_λ [10^-12 W m^-2]
0.02 0.04 0.06 0.08 0.1
10 20 30
λ [μm]


hv2255
log λ F$_λ$ [W m^{-2}]
−15
−14
−13
−12
0
1
2
log λ [μm]
λ F$_λ$ [10^{-12} W m^{-2}]
0.1
0.2
0.3
10
20
30
λ [μm]

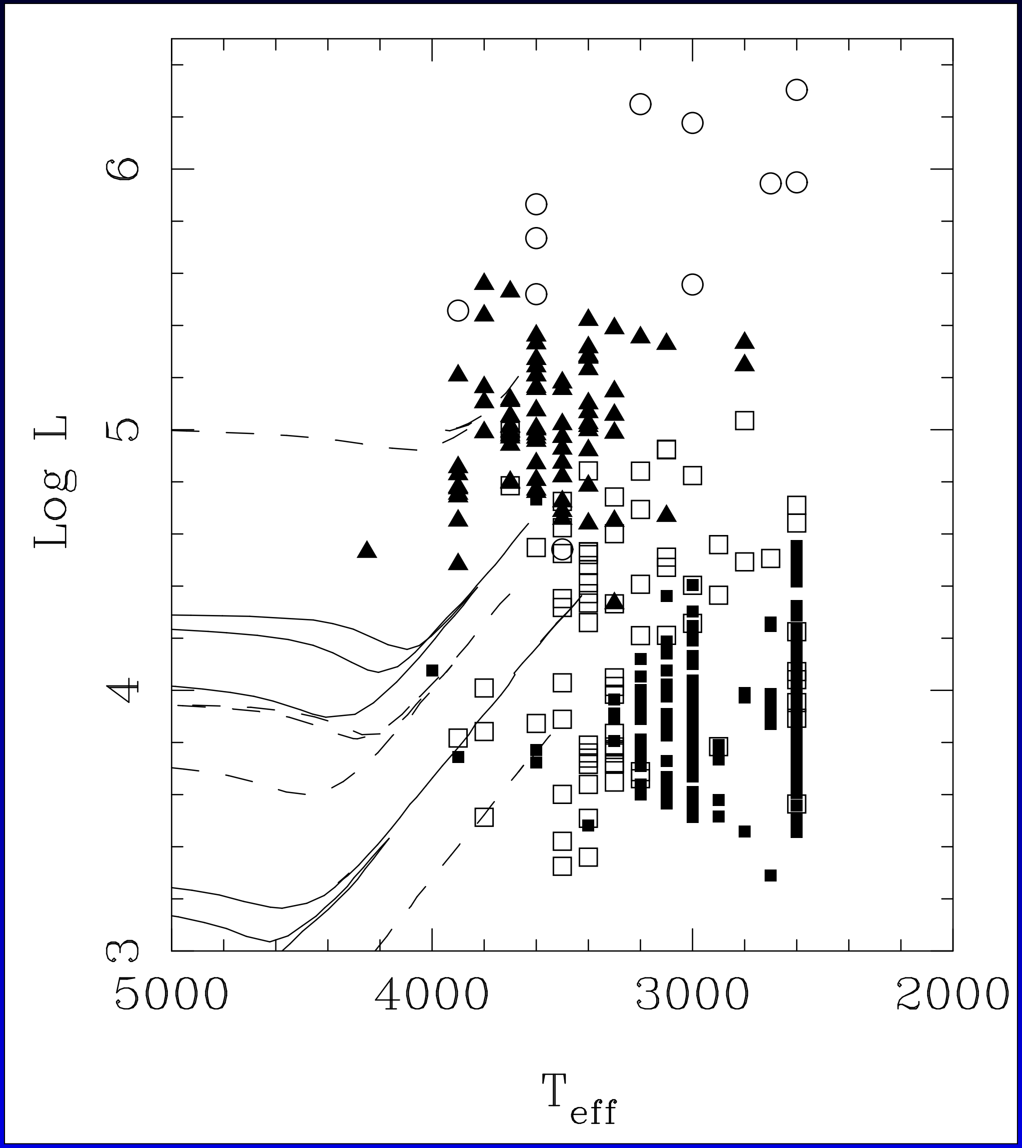

iras05402
log λ F$_λ$ [W m^{-2}]
−16 −15 −14 −13 −12
0 1 2
log λ [μm]
λ F$_λ$ [10^{-12} W m^{-2}]
0.1 0.2 0.3 0.4
10 20 30
λ [μm]

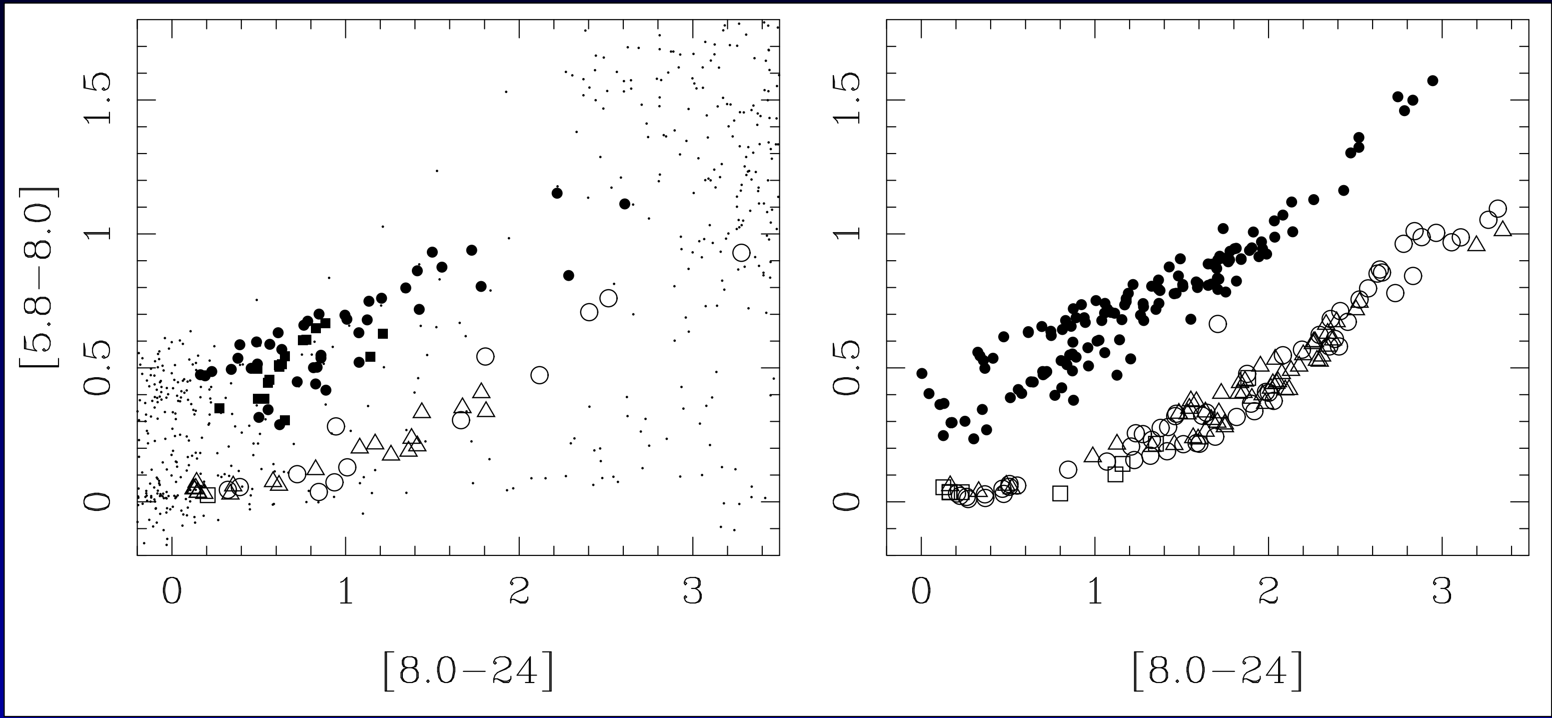
CMD



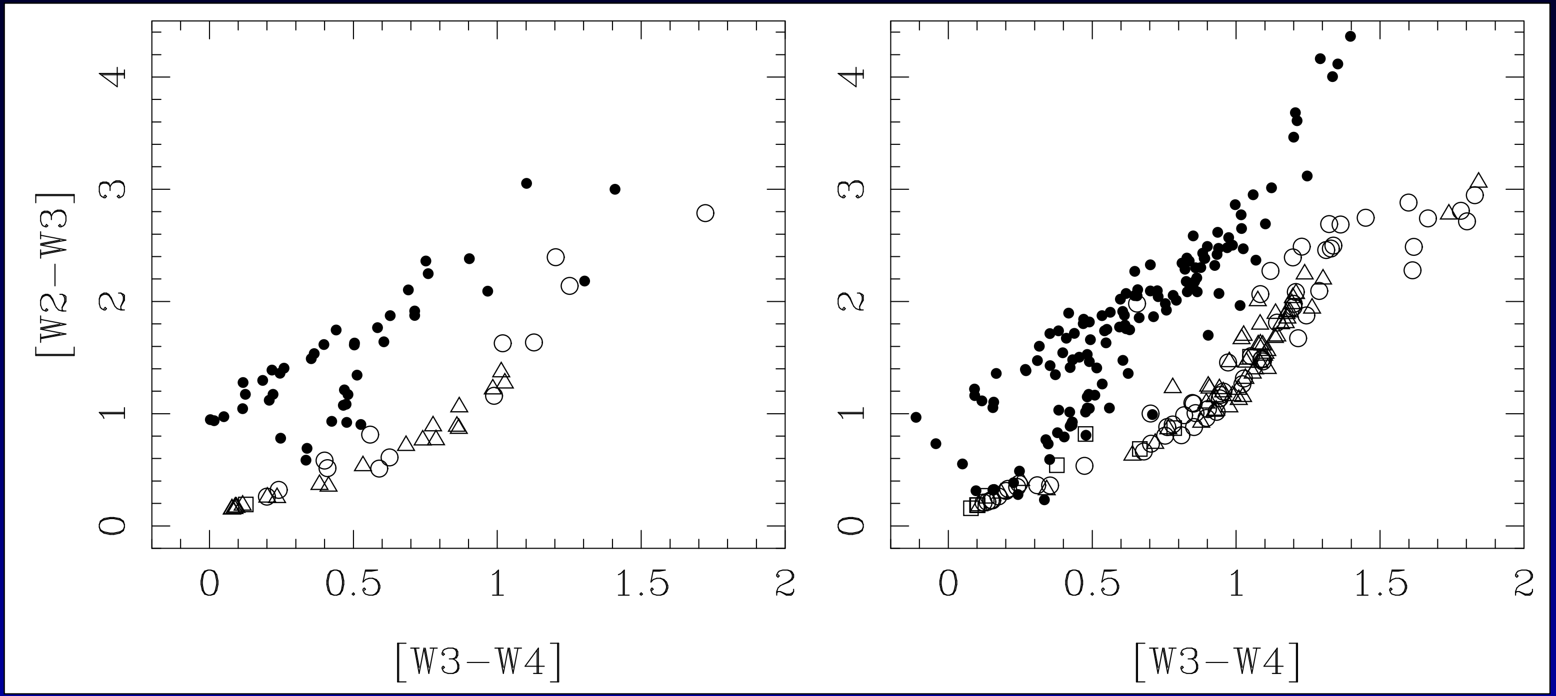
SMC: left ; LMC: right. Offset 0.5 mag

HRD

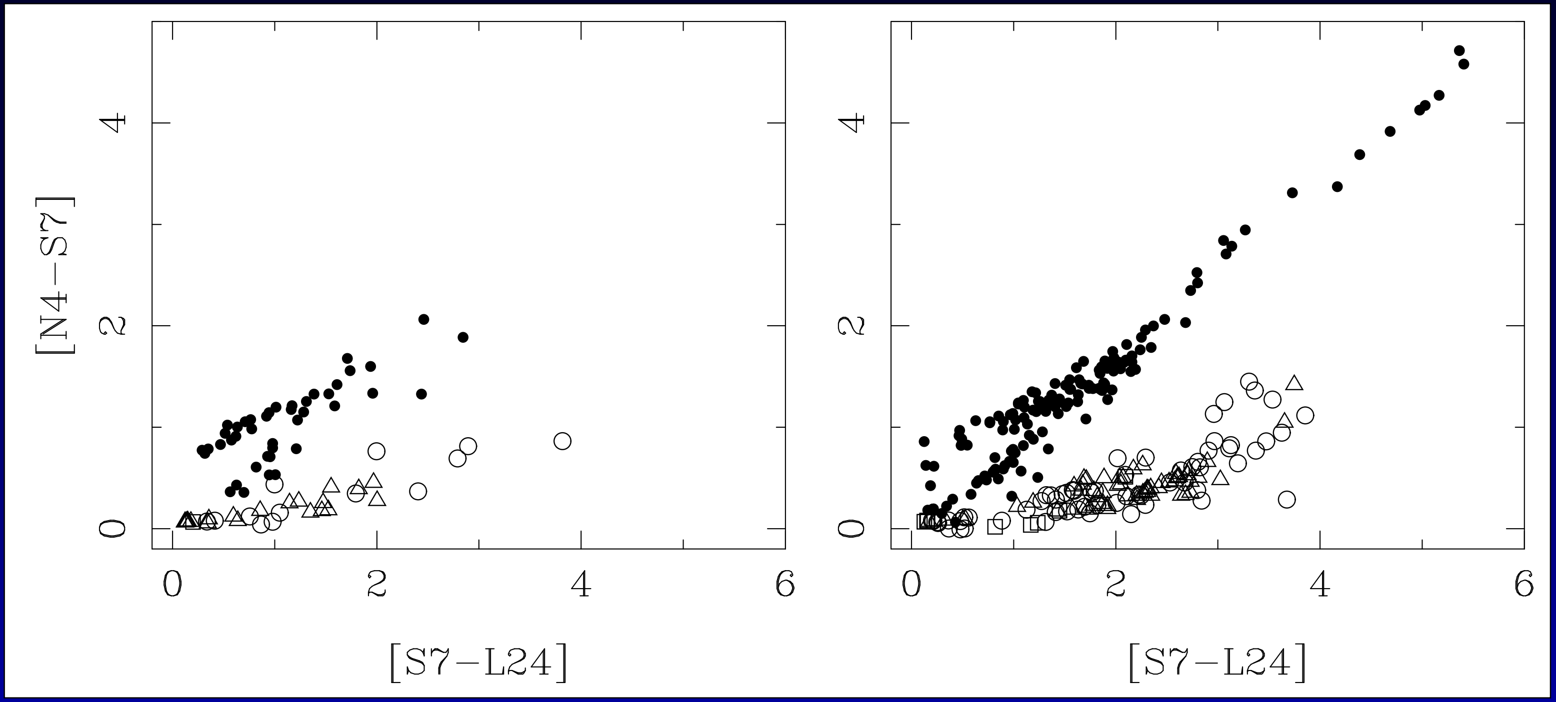




good separation between C- and O-rich using IRAC/MIPS !
C-stars (filled symbols), O-stars (open symbols)
SMC: left ; LMC: right.

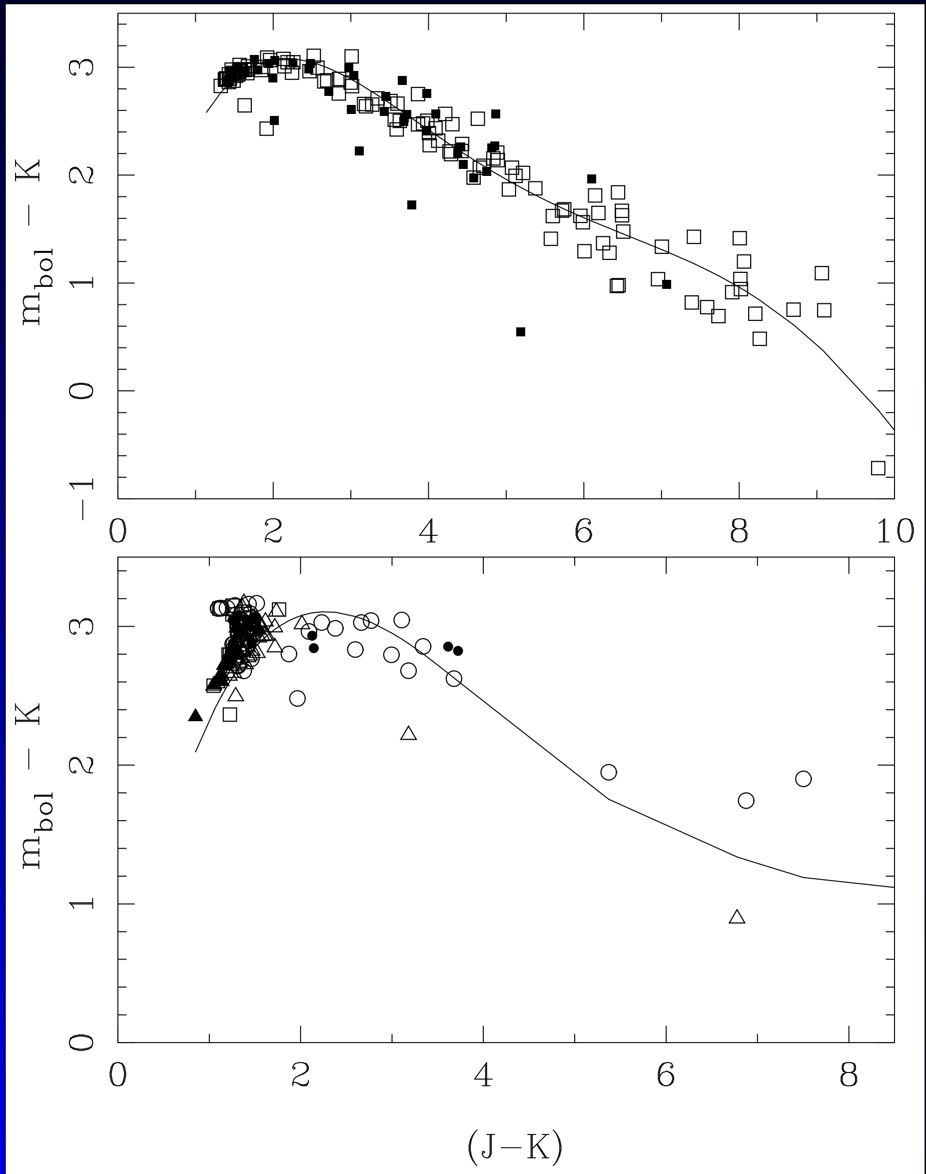


WISE: similar colours, seperation is less good.



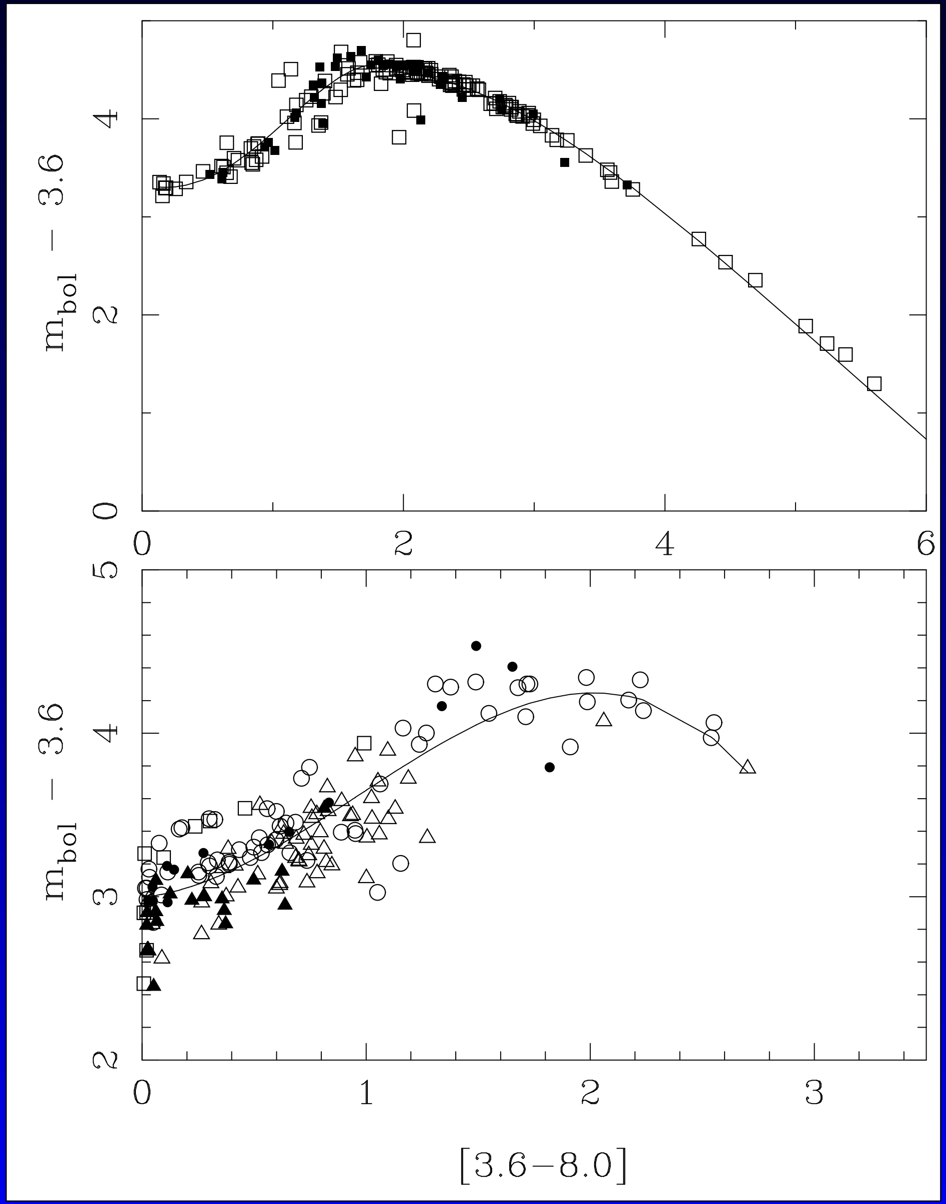
Akari: similar colours, separation is less good.

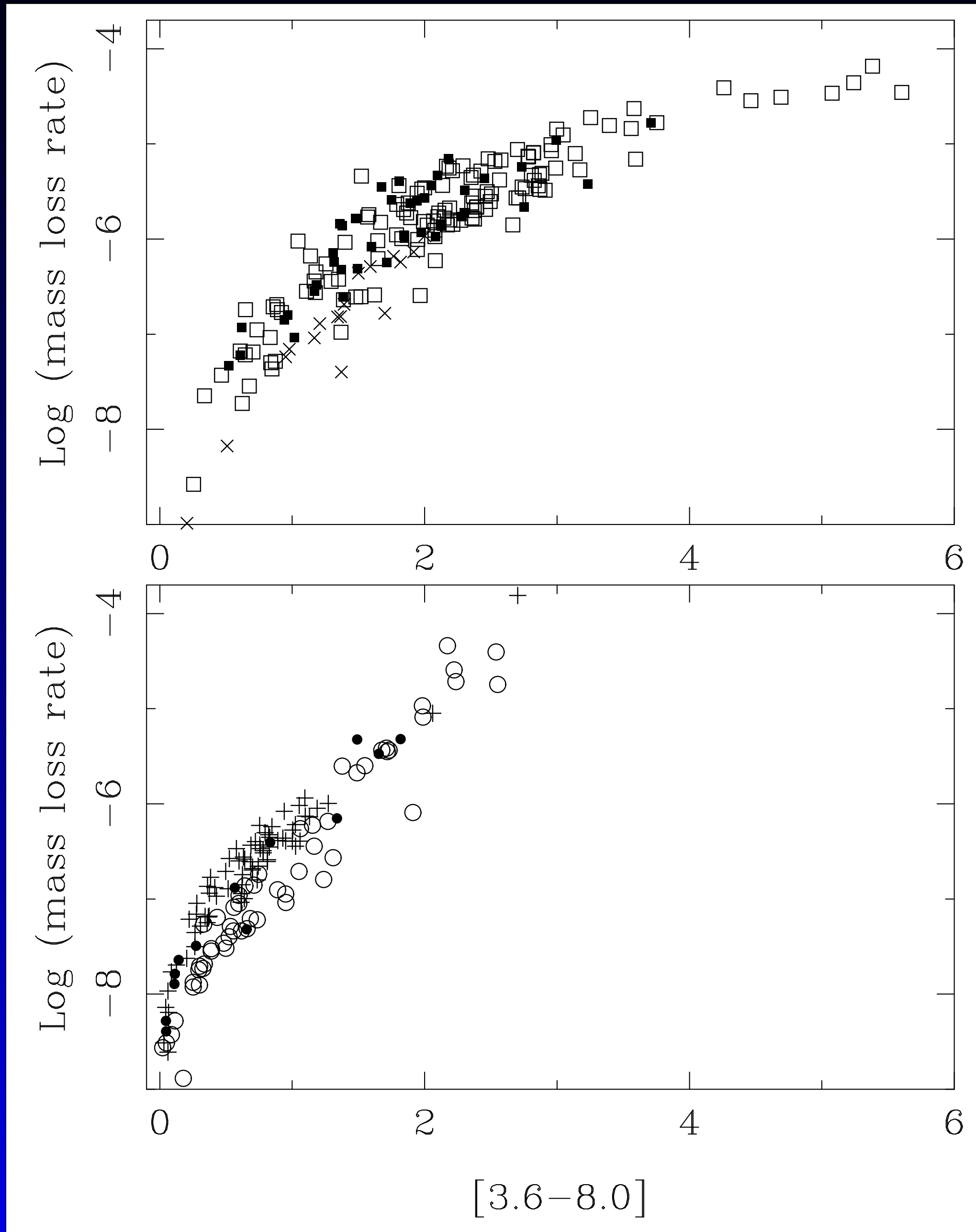
Bolometric Corrections



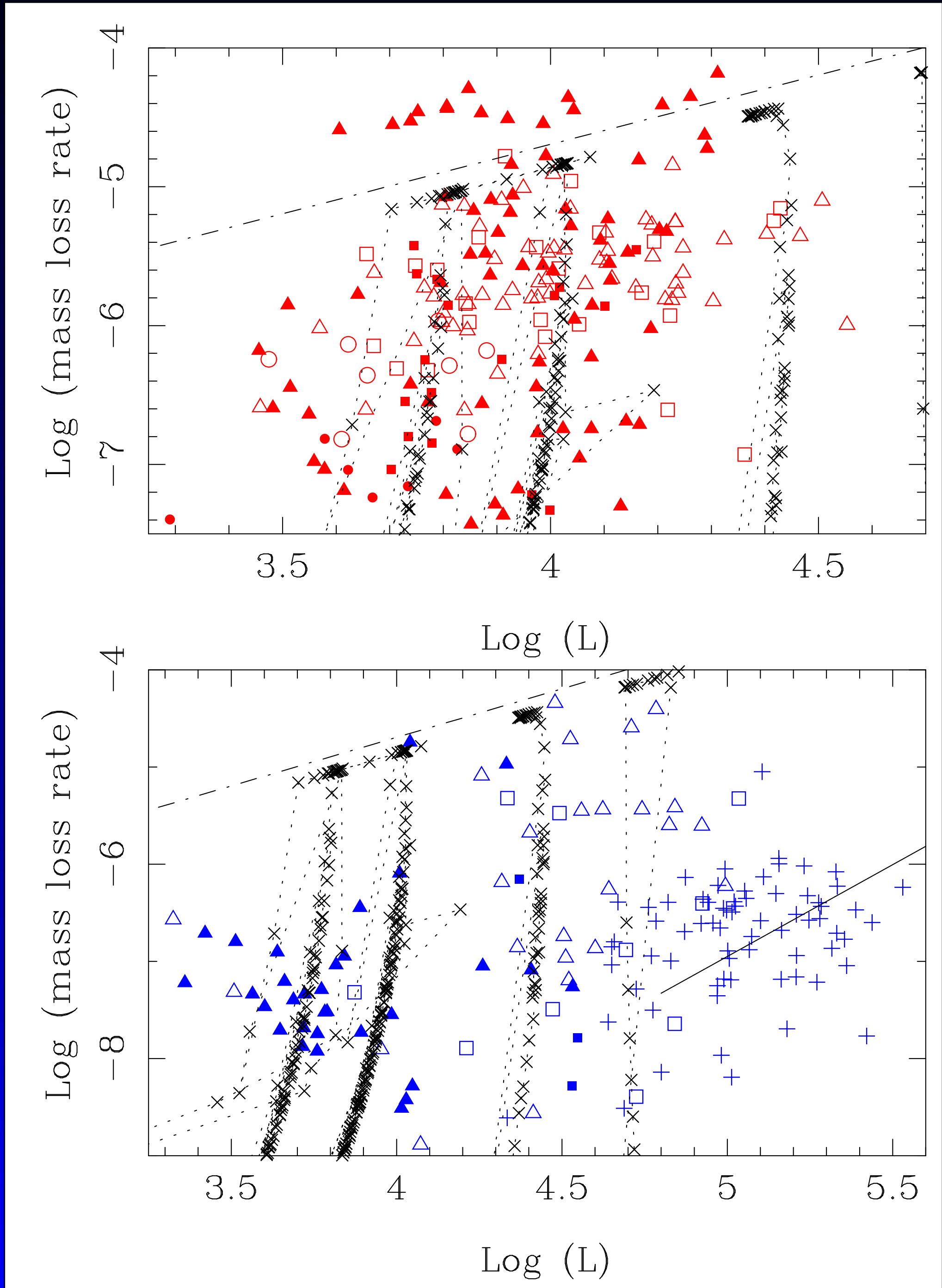
C-stars (upper), O-stars (lower panel)

Bolometric Corrections





C-stars (upper), O-stars (lower panel)


Log (mass loss rate)
−4
−5
−6
−7
3.5
4
4.5
Log (L)
Log (mass loss rate)
−4
−6
−8
3.5
4
4.5
5
5.5
Log (L)

Mass-loss formula

Vassiliadis & Wood (1993)

$$\dot{M} = -11.4 + 0.0123P \quad (1)$$

$$\dot{M} = L/(c\, v_{\rm exp}) \quad (2)$$

$\dot{M}$ used is minimum of (1,2)

$v_{\rm exp} = -13.5 + 0.056P$ (and in range 3-15 km/s)

$$\log P = -2.07 + 1.94 \log R - 0.9 \log M$$

Summary and Prospects

- Fitting SEDs (w. or w/o spectroscopy) is a relatively simple way to have an estimate of the (dust) mass-loss rate.
  With current data its possible to do this out to IC 10 (715 kpc, LeBouteiller et al.)
- $\dot{M}$ - colour, some C-C, and BC relations, can be used to estimate chemical type, L, and MLR
- Nature of these very high MLR sources ?
  Are they variable ?
  Mass-loss recipes in stellar evolution calculation may need revision

Summary and Prospects

- V_∞, Dust-to-gas ratio, and dependence on Z, or L

  V_∞ from ALMA

  Test dust driven wind theory

  Gas mass-loss rates (and thus Ψ) from detailed modelling of CO lines

  Parallel efforts ongoing:
  MCs, Clusters, Halo C-stars
  (none in Cycle-0, resubmitted in Cycle-1)

THE END