Exploiting long period variables: the past and the future

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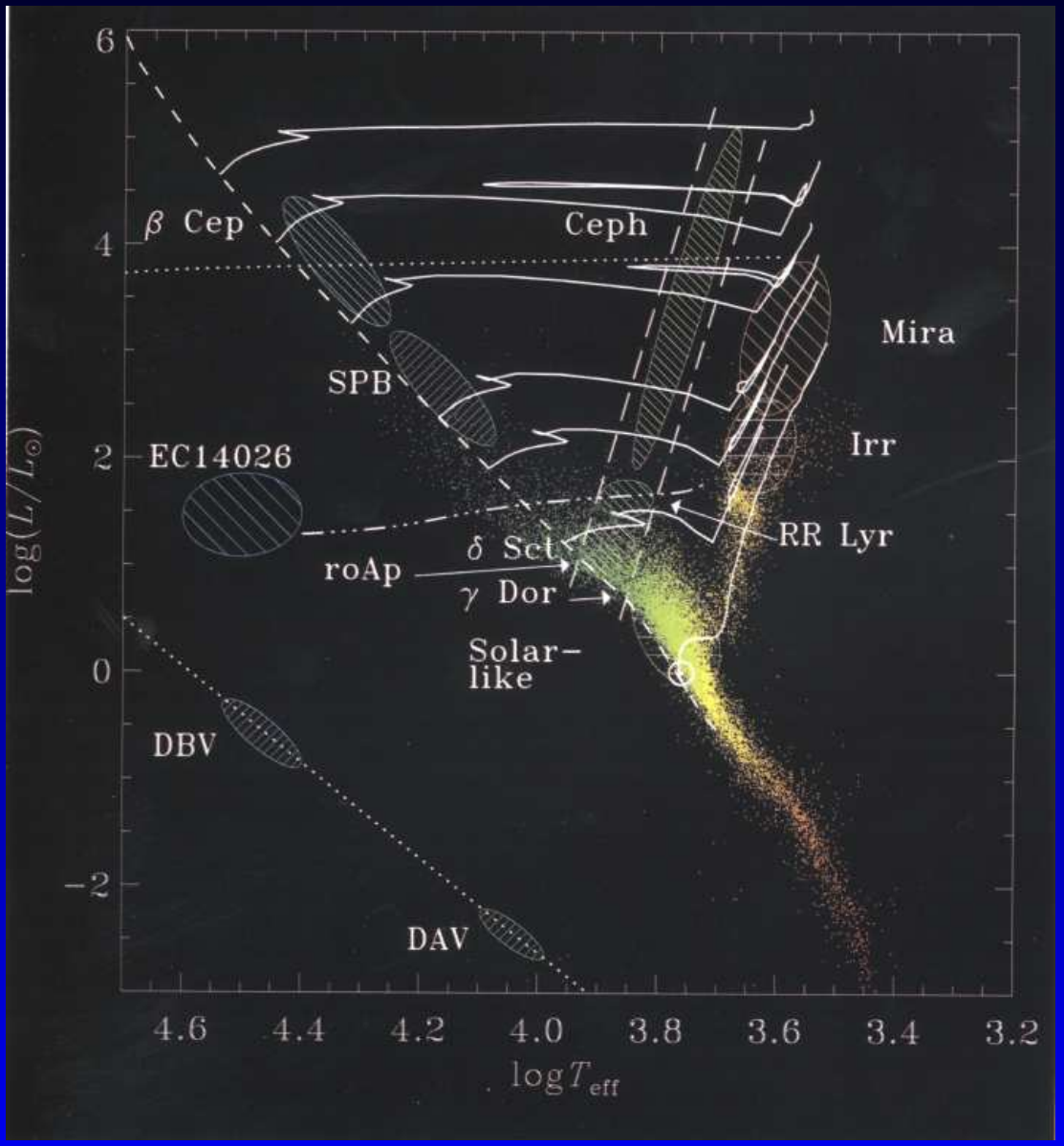
Overview Talk

- Introduction to AGB stars, Miras, Long Period Variables (LPVs)
  - Period-Luminosity relation
  - Distance Indicator
- Past
- Future
- Summary and Conclusions

AGB stars


6
4
2
0
−2
log(L/L⊙)
β Cep
Ceph
Mira
SPB
EC14026
Irr
RR Lyr
δ Sct
roAp
γ Dor
Solar-
like
DBV
DAV
4.6
4.4
4.2
4.0
3.8
3.6
3.4
3.2
log T_eff

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)

AGB characteristics

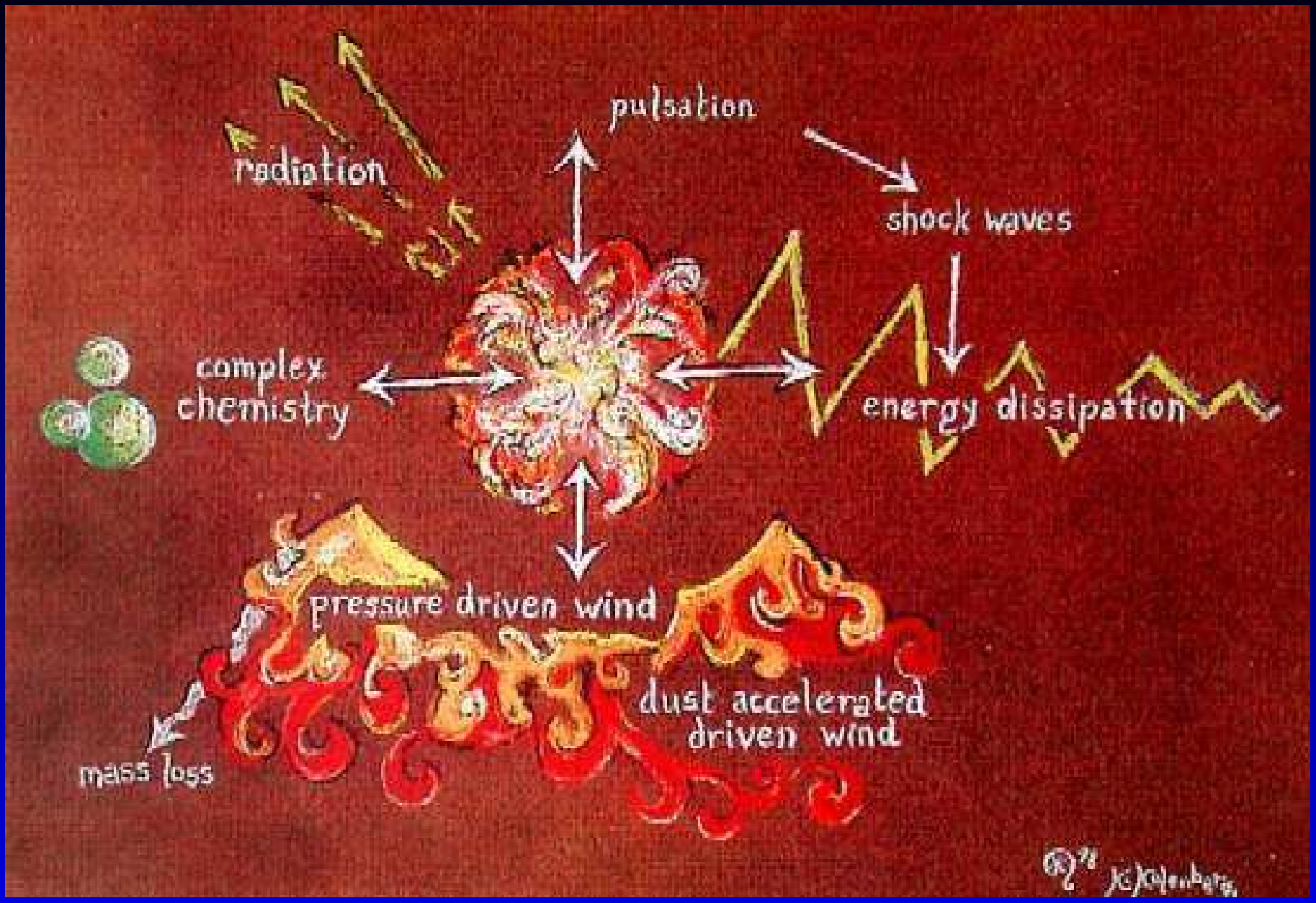
- Chemical type: M, S, C

  Complication: HBB (C $\Rightarrow$ O)

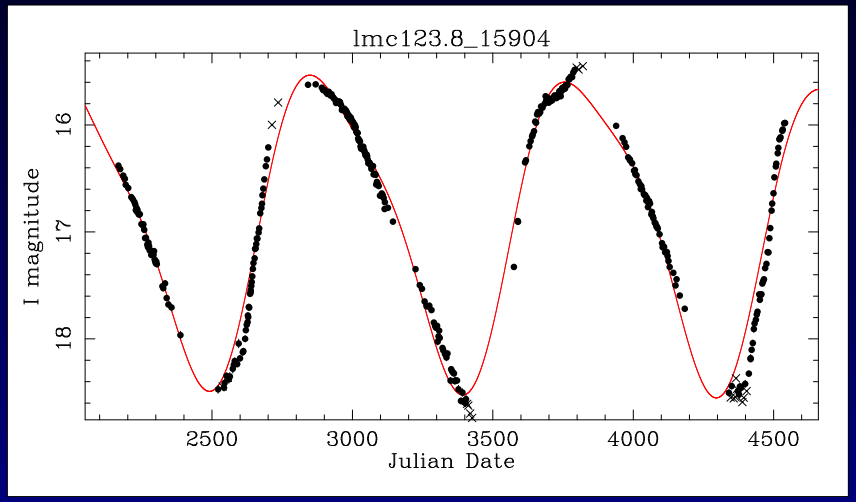
- Pulsate: Irr, SR, Miras (LPVs)

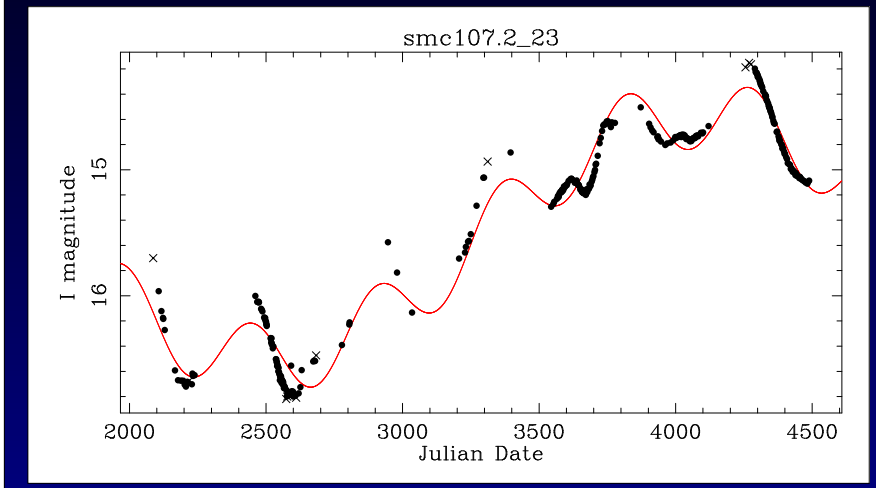
  Definition of a Mira $\Delta V > 2.5$ & Regular, $\Delta I > 0.8$, $\Delta K >$0.4

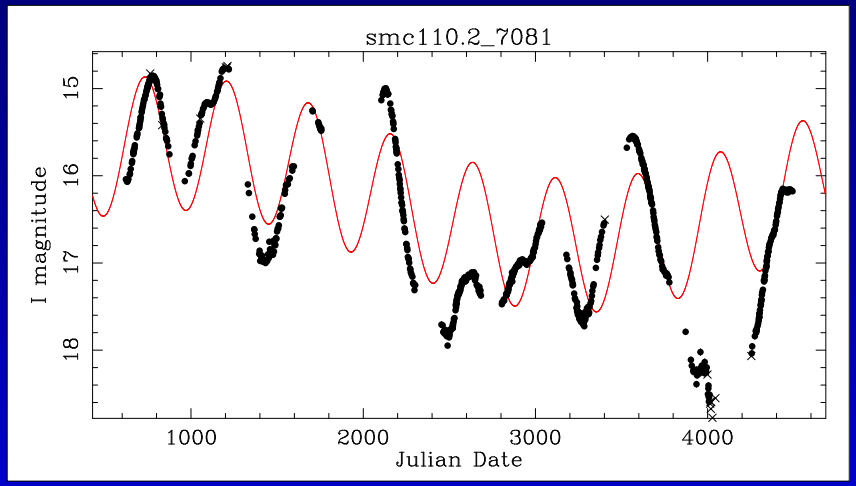
- Mass-loss (effect on colours)

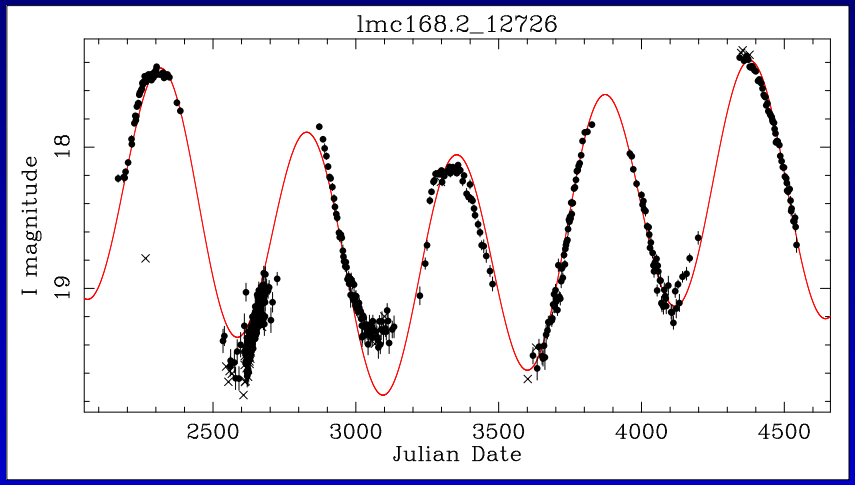

pulsation
radiation
shock waves
complex chemistry
energy dissipation
pressure driven wind
dust accelerated driven wind
mass loss

Lightcurves









Example of OGLE II + III *I*-band lightcurves
-Main Period (50-2000 days)
-Long Secondary Period (LSP)

Distance Indicator

Cepheid $M_K = -3.33(\log P - 1) - 5.66$
(Storm et al. 2011)
Cepheid P= 50d: $M_{\rm K} = -8.0$
LPV P= 400d: $M_{\rm K} = -8.0$

At 3.6 micron:
Cepheid $M_{3.6} = -3.31(\log P - 1) - 5.80$
(Freedman et al. 2012)
Cepheid P=50d: $M_{\rm K} = -8.1$
LPV $M_{3.6} = -3.41 \log P + 0.39$
(O-rich, DM=18.50; Riebel et al. 2010)
LPV P= 400d: $M_{\rm K} = -8.5$

Distance Indicator

Cepheid versus LPVs

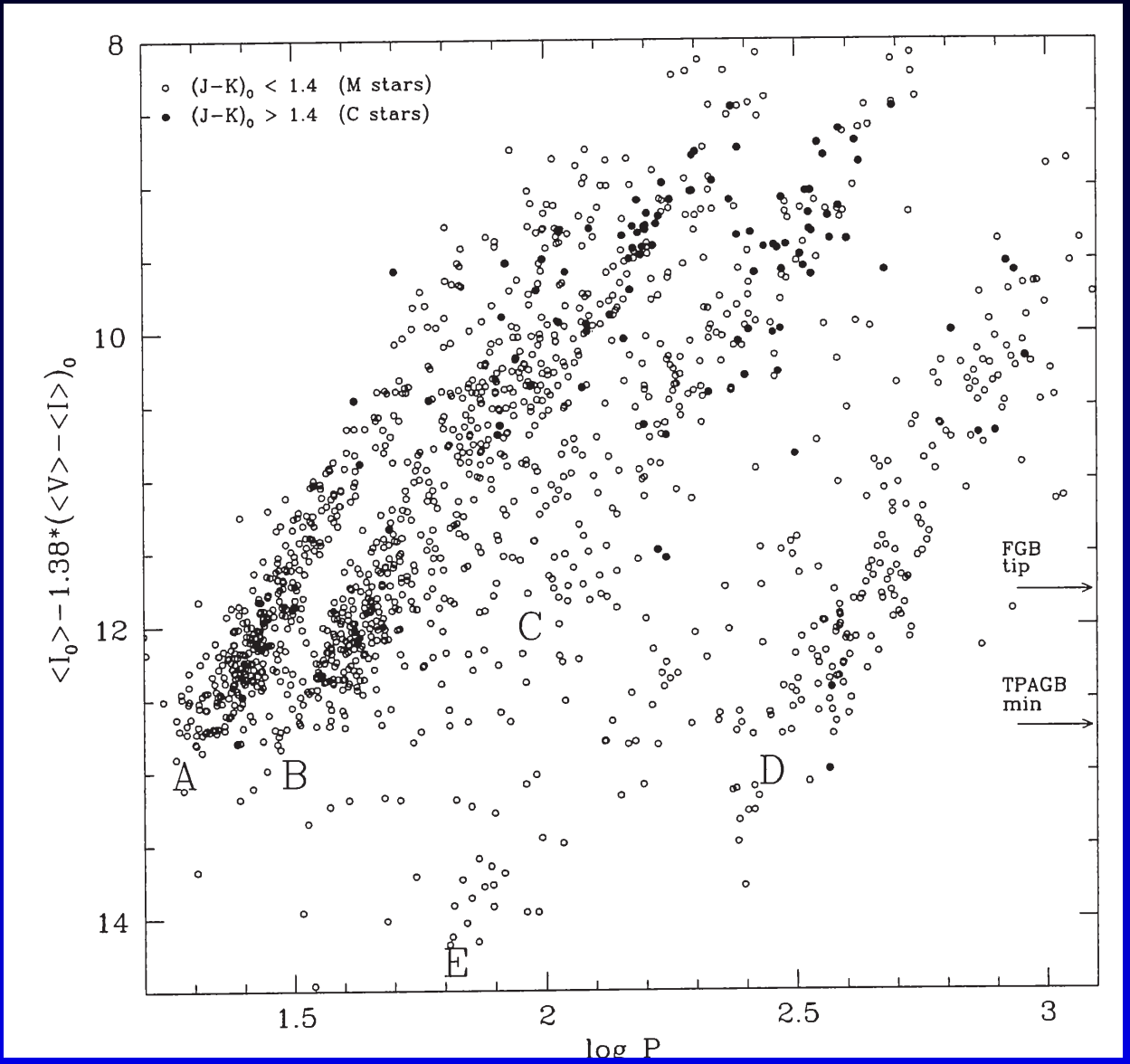
LPVs are brighter, older population than cepheids, less concentrated in spiral arms (crowding, blending)

Takes longer to get the lightcurve of an LPV, and they have less regular lightcurves

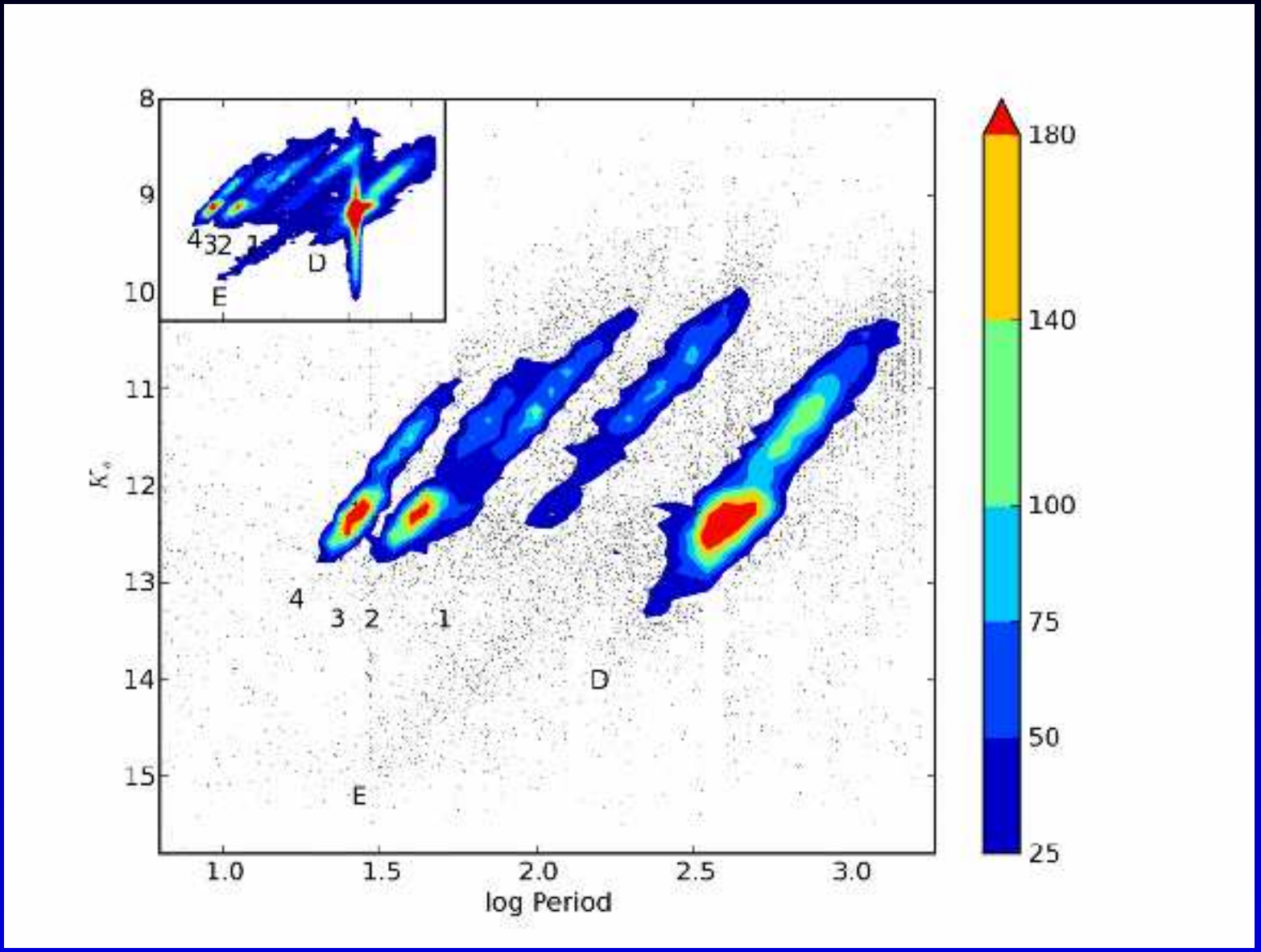
For both CS reddening can be an issue
(cepheids for $\lambda \gtrsim 3.6 \mu$m; LPV any "red" colour)

For LPVs one can circumvent this by using $m_{\rm bol}$, but difficult to get $m_{\rm bol}$ properly (BC are less secure)

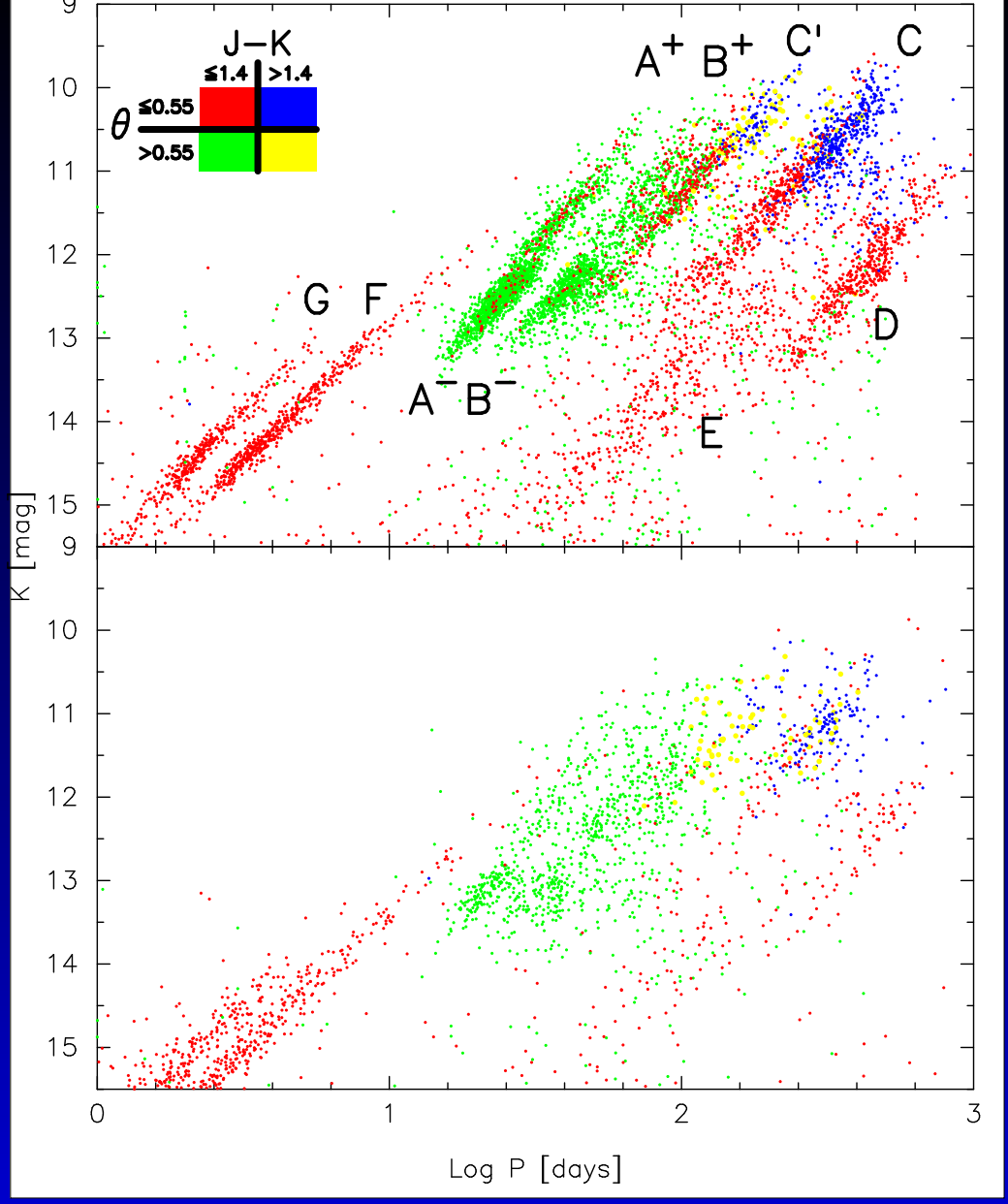
The Past



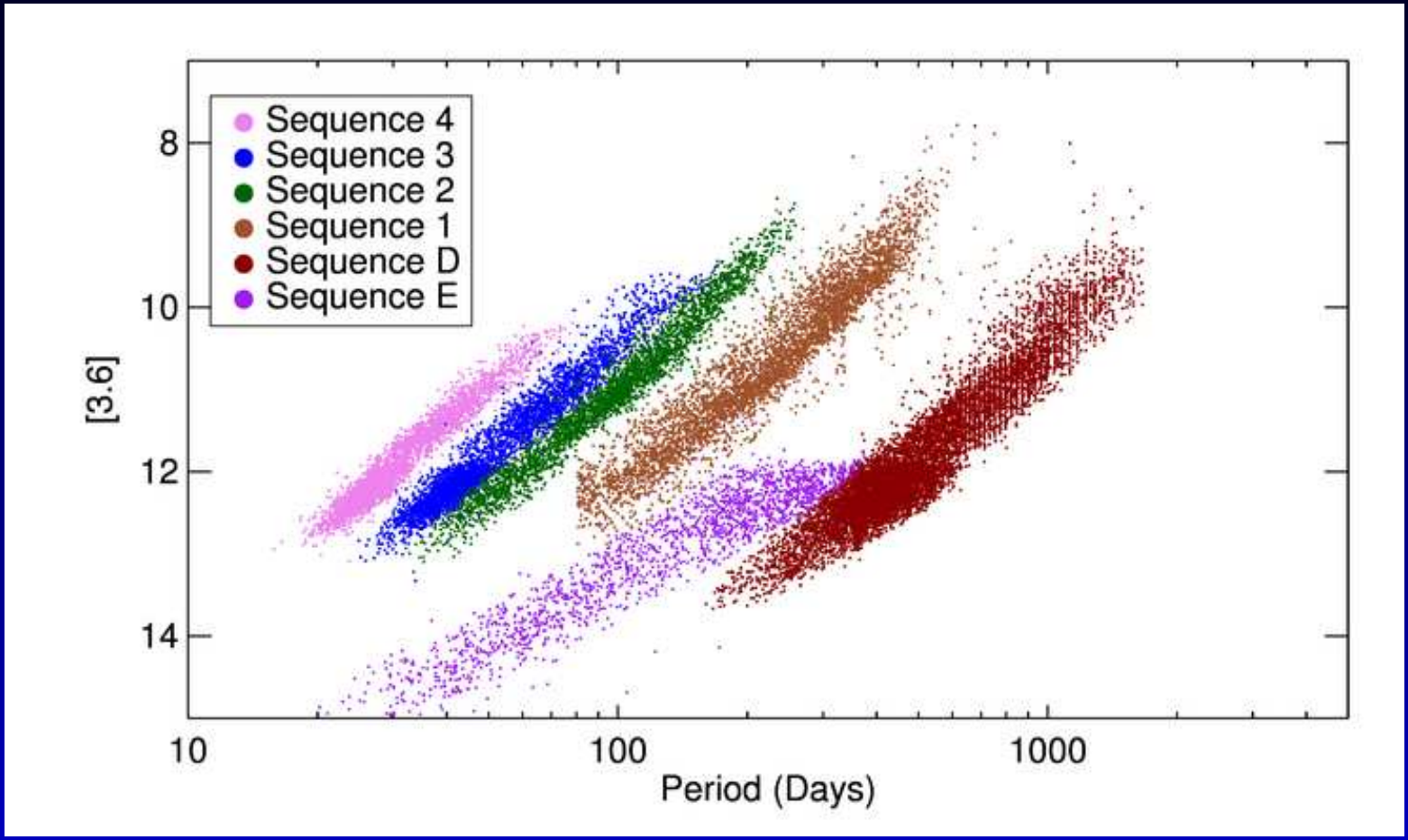
Wood et al. (1999). $W = I - 1.38\,(V - I)$



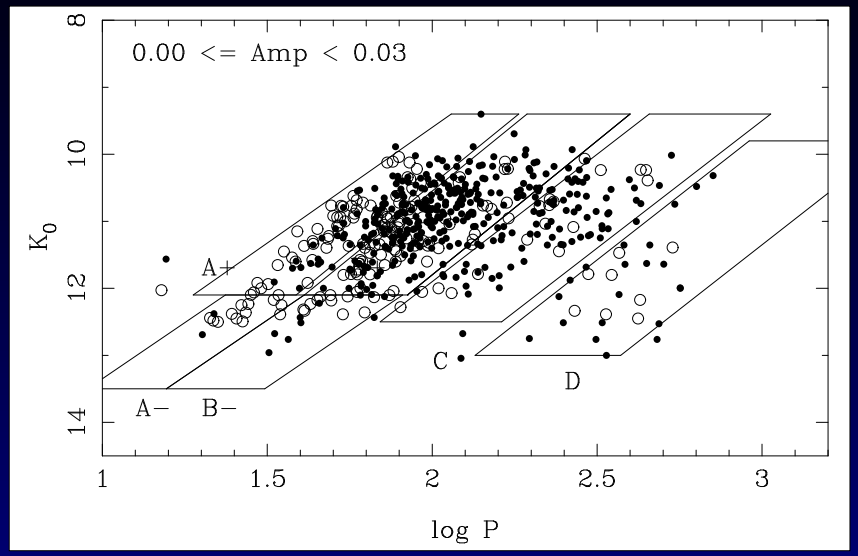
Fraser et al. (2008). MACHO + 2MASS

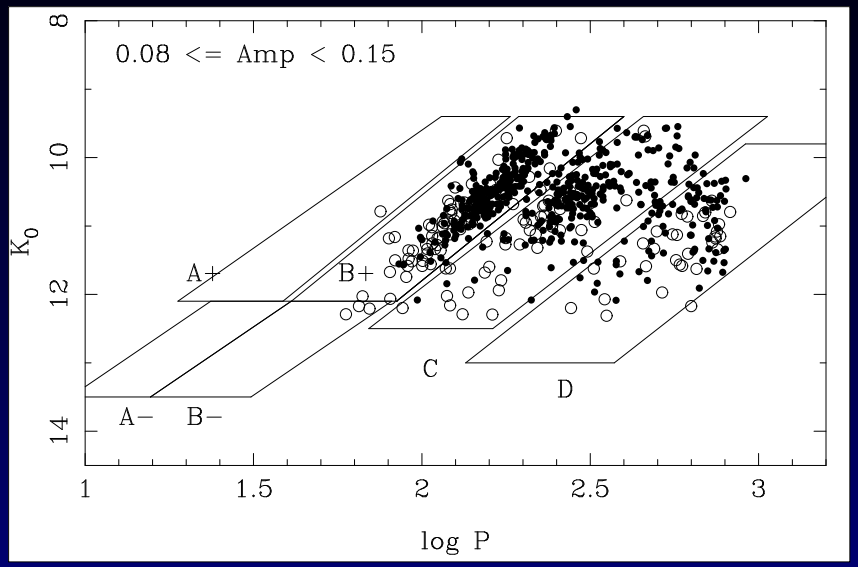


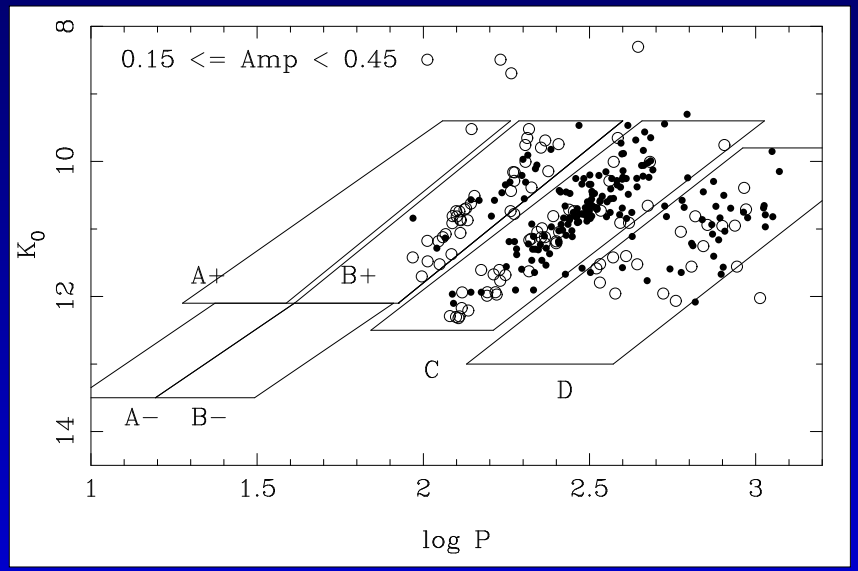
Ita et al. (2004). LMC (upper), SMC (lower)
$\theta > 0.55$ "regularly pulsating variables"
OGLE-II + SIRIUS

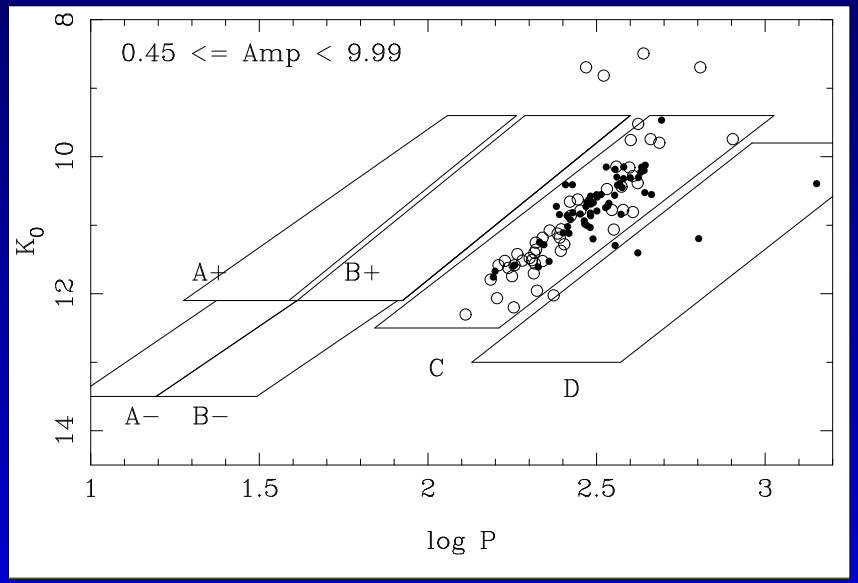


Riebel et al. (2010).
MACHO (Fraser et al. 2008) + SAGE (average of 2 epochs).
(SAGE-VAR 4 additional epochs over smaller area)









LMC LPVs from Groenewegen (2004).
OGLE-II + 2MASS.
$PL(K)$-relation for different cuts in amplitudes

PL-relations

- Feast et al. (1989, MN 241, 375)

  $M_{\rm bol} = -3.00 \log P + 21.35$ (29 LMC O-Miras, rms=0.16)

  $M_{\rm bol} = -1.86 \log P + 18.73$ (20 LMC C-Miras, rms=0.13)

  $M_{\rm K} = -3.47 \log P + 19.48$ (29 LMC O-Miras, rms=0.13)

  $M_{\rm K} = -3.30 \log P + 18.98$ (20 LMC C-Miras, rms=0.18)

- Groenewegen & Whitelock (1996, MN 281, 1347)

  $M_{\rm bol} = -2.59 \log P + 20.52$ (54 LMC C-Miras, rms=0.26)

  $M_{\rm K} = -3.56 \log P + 19.64$ (54 LMC C-Miras, rms=0.25)

- Whitelock et al. (2008, MN 386, 313)

  $M_{\rm K} = -3.51 \log P + 19.59$ (31 LMC O-Miras, rms=0.14)

  $M_{\rm K} = -3.52 \log P + 19.53$ (22 LMC C-Miras, rms=0.15)

PL-relations - microlensing

- Groenewegen et al. (2004, A&A 425, 595)

  $M_{\rm K} = (-3.78 \pm 0.24) \log P + (20.17 \pm 0.58)$

  (O-rich, rms=0.26, Ampl)

  $M_{\rm K} = (-3.50 \pm 0.27) \log P + (19.42 \pm 0.67)$

  (C-rich, rms=0.26, Ampl)

  Ita et al. (2004, MN 353, 705)

  $M_{\rm K} = (-3.59 \pm 0.06) \log P + (19.70 \pm 0.13)$

  ("O-rich", rms=0.20, $J-K<1.4$)

  $M_{\rm K} = (-3.37 \pm 0.10) \log P + (19.17 \pm 0.25)$

  ("C-rich", rms=0.25, $J-K>1.4$)

  Fraser et al. (2008, AJ 136, 1242)

  $M_{\rm K} = (-3.67 \pm 0.0?) \log P + (19.72 \pm 0.0?)$

  ("O-rich", rms=0.?, Ampl)

  $M_{\rm K} = (-3.16 \pm 0.0?) \log P + (18.53 \pm 0.??)$

  ("C-rich", rms=0.?, Ampl)

  Riebel et al. (2010, ApJ 723, 1195)

  $M_{\rm K} = (-3.31 \pm 0.04) \log P + (18.87 \pm 0.09)$

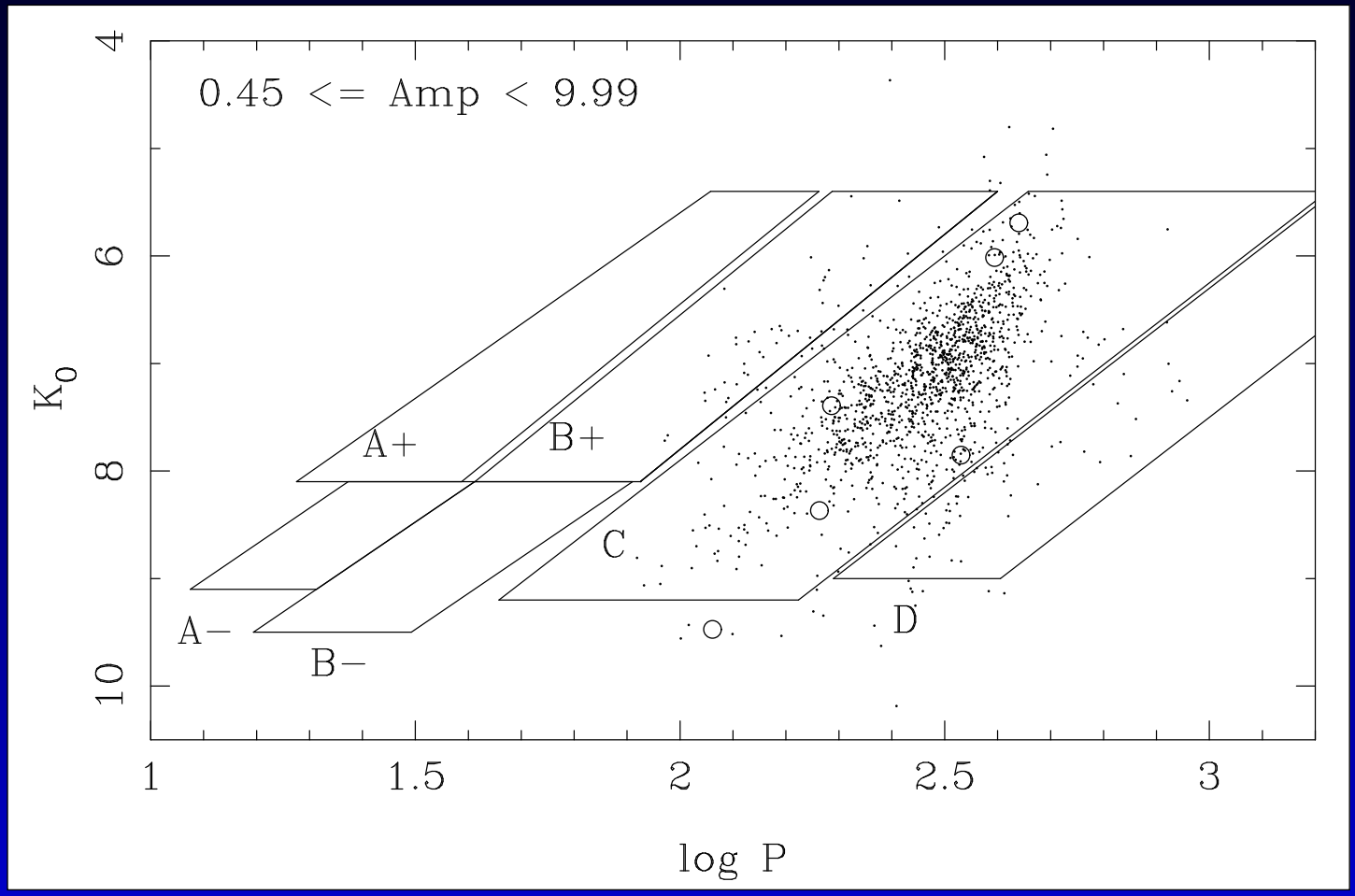
  (O-rich, rms=0.27)

  $M_{\rm K} = (-3.16 \pm 0.04) \log P + (18.40 \pm 0.11)$

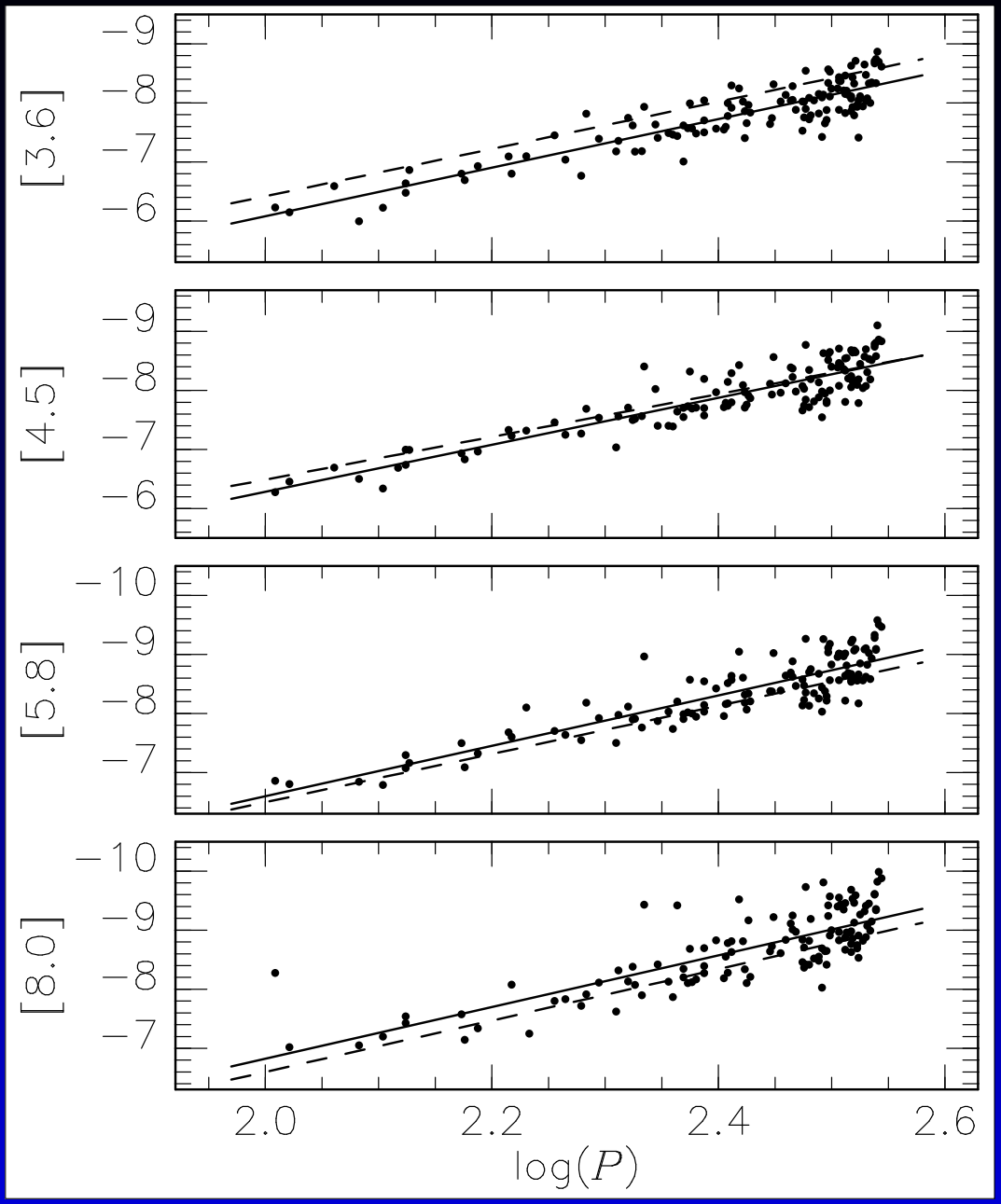
  (C-rich, rms=0.23)

  But, SINGLE Epoch IR data

Applications

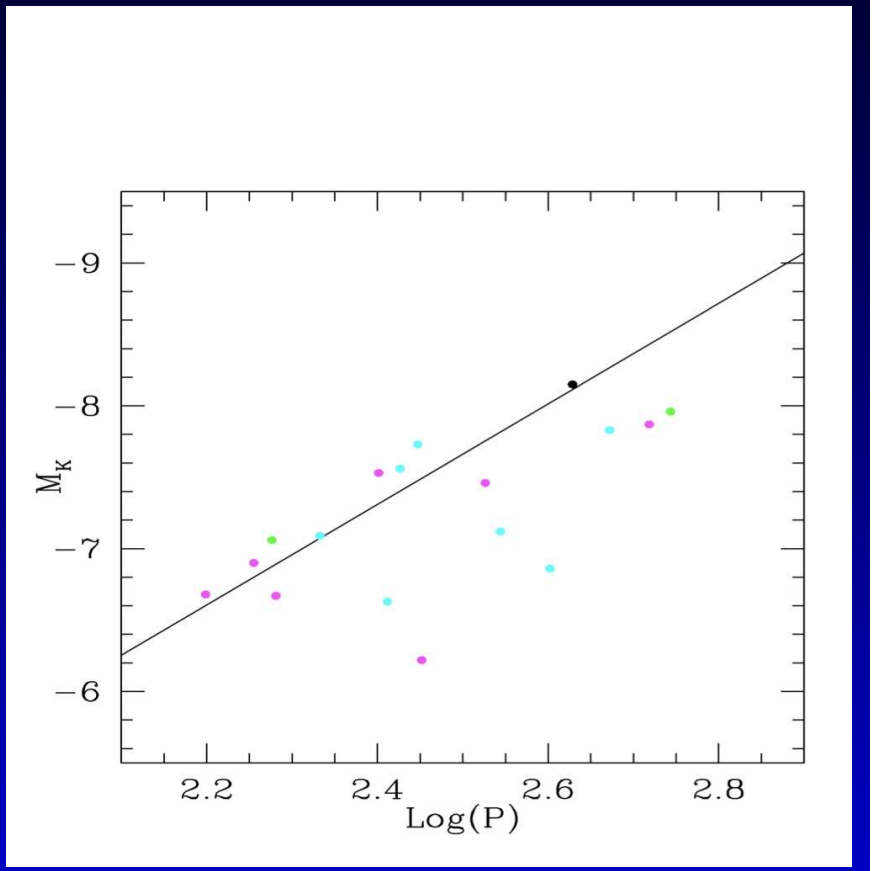


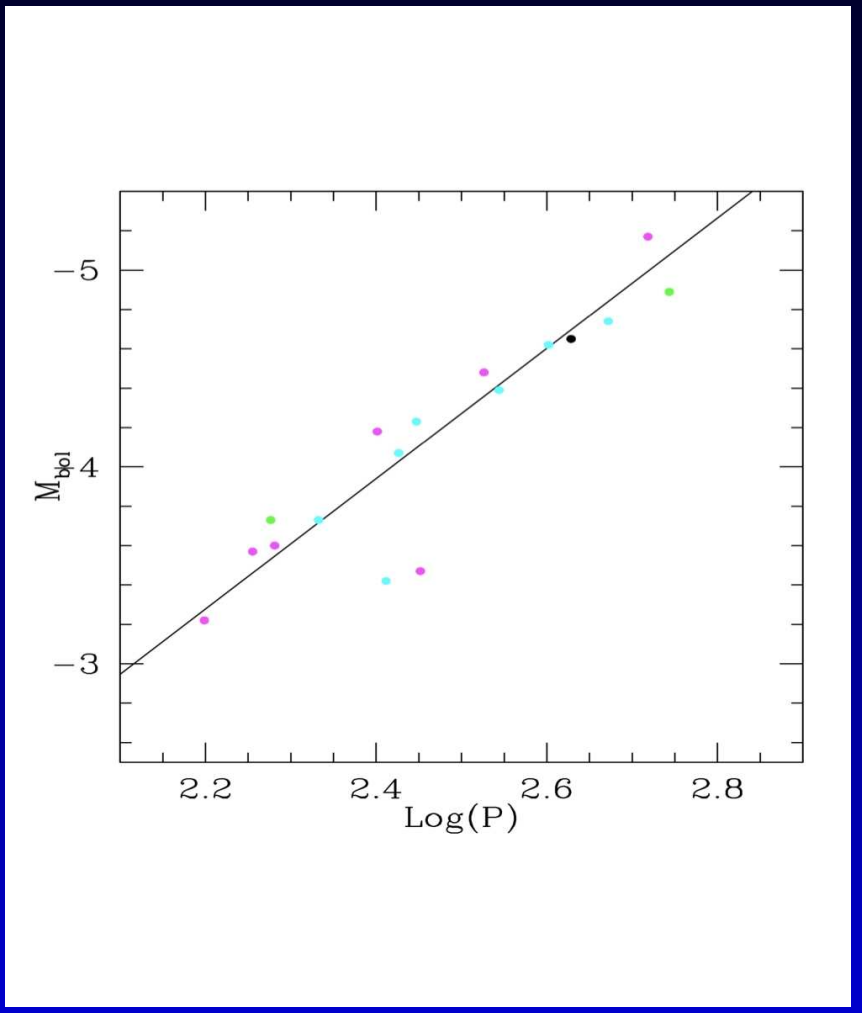
Bulge Miras from Groenewegen & Blommaert (2005).
OGLE-II + 2MASS



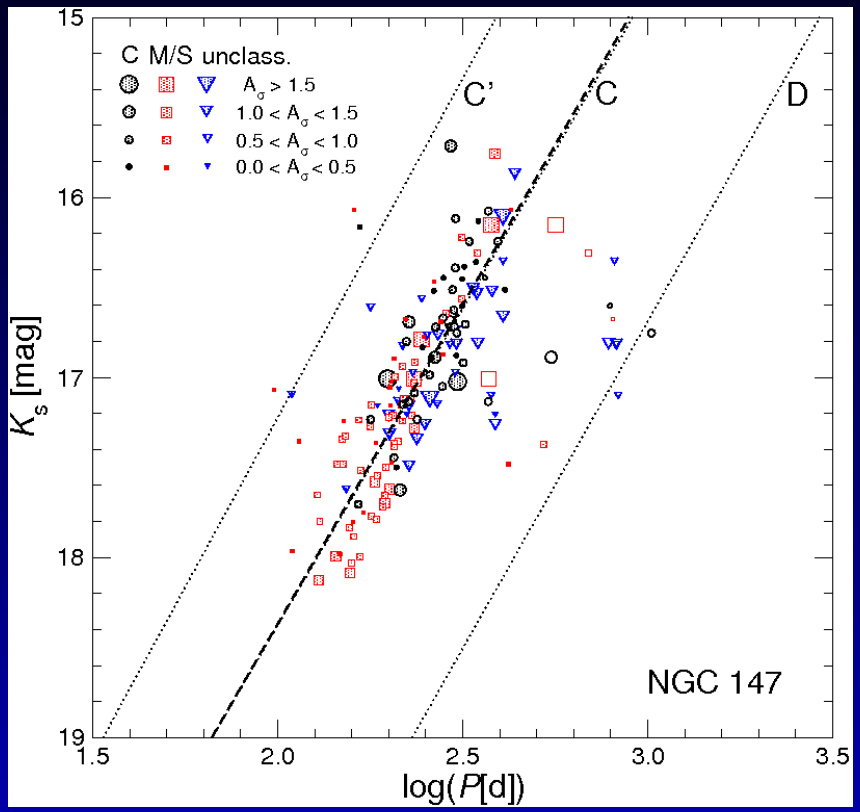
Galactic Centre Miras from Matsunaga et al. (2009). survey of 20x30 arcmin^2 with SIRIUS.

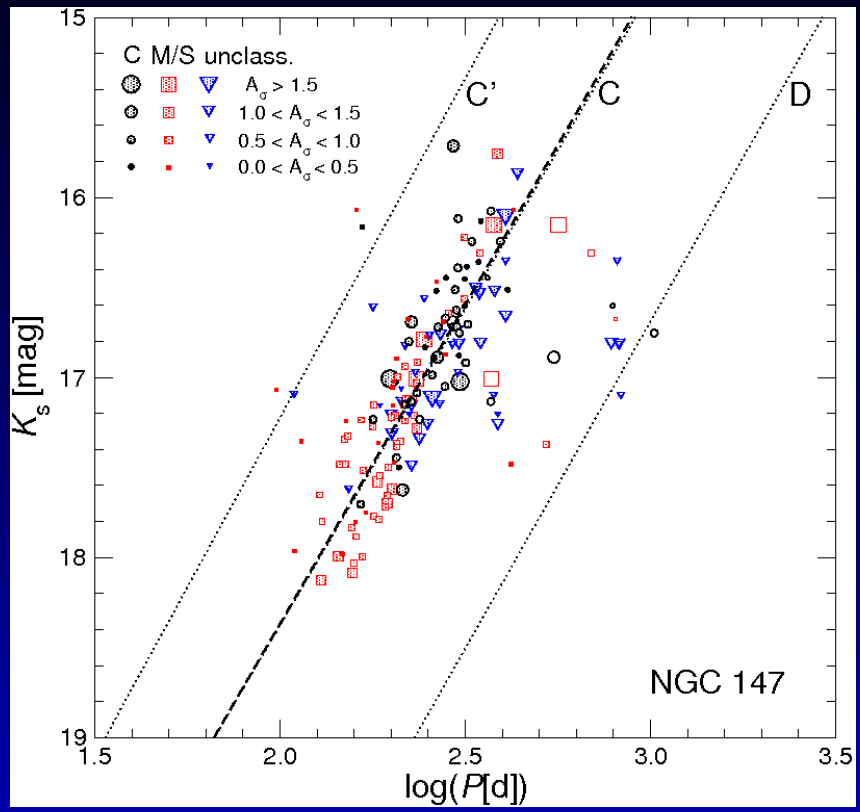
DSphs Local Group



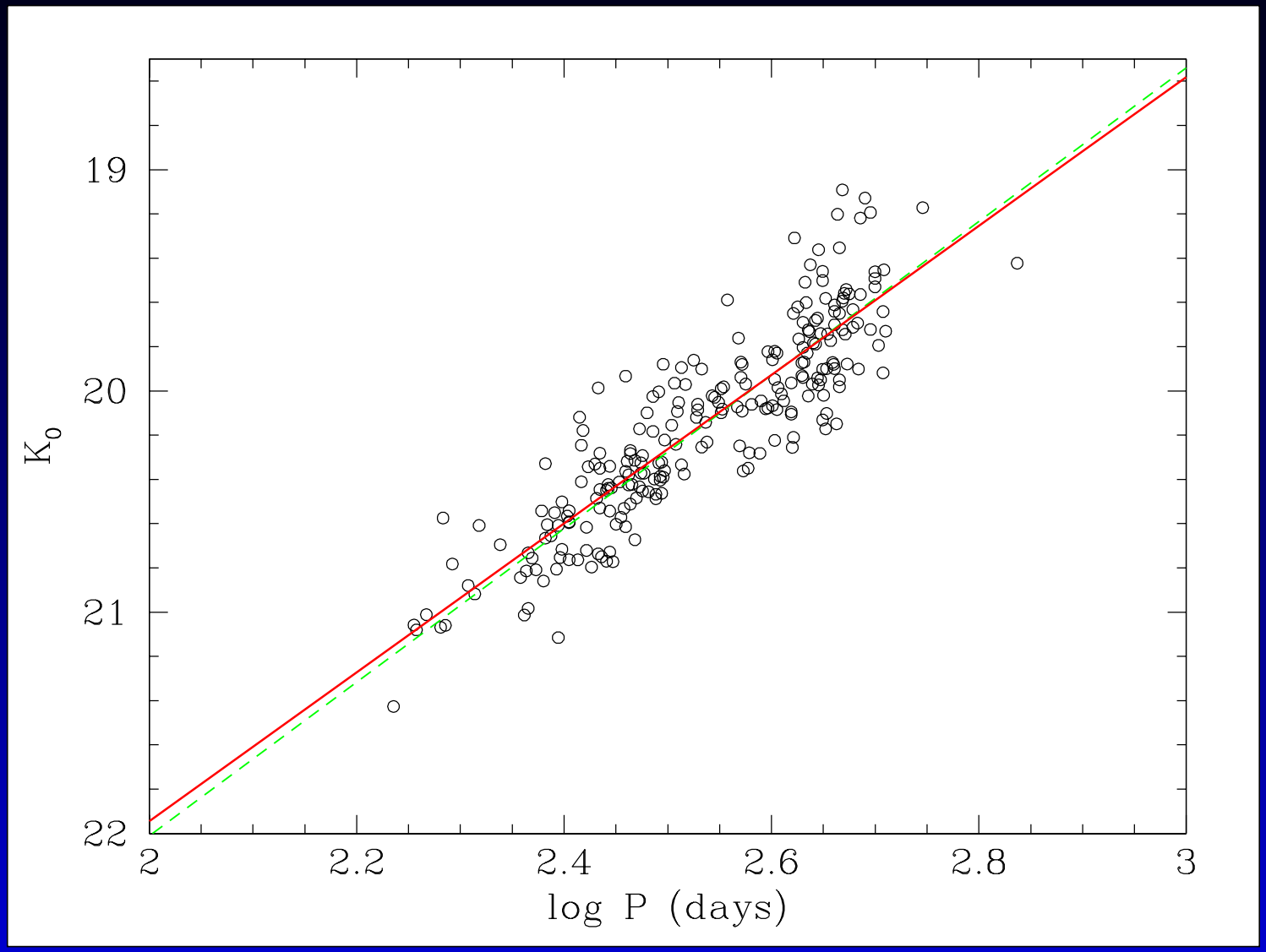


Whitelock et al. (2011).
Fornax (7), Leo I (7), Scl (2), Phoenix (1)





Lorentz et al. (2011).
NGC 147 and 185. d= 725 kpc.
Variability in I + single-epoch K.



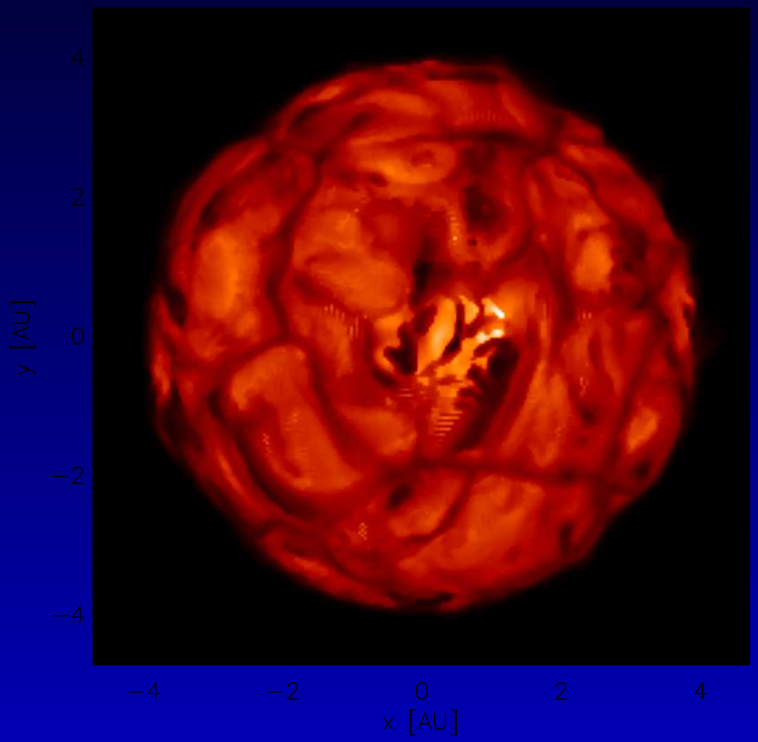
NGC 5128 from Rejkuba (2004).
K-band monitoring.
TRGB & Miras to find d= 3.8 Mpc.

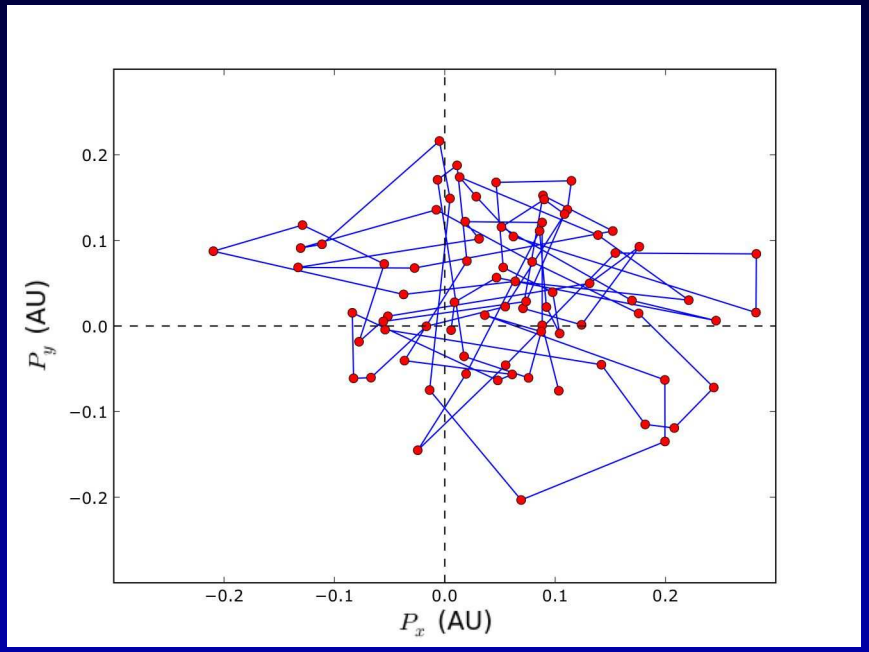
Future: GAIA

- Robin et al. 2012 A&A 543, A100
  Gaia Universe Model Snapshot
  $G < 20$ Total= 1100M; 0.19% of 21.5M = 41000
  $G < 17$ Total= 390M; 0.24% of 16M = 38000
  $G < 12$ Total= 13M; 0.91% of 2M = 18000
- An issue:
  angular diameter $>$ parallax

  1 AU = 215 $R_\odot$

Size Problem





Chiavassa et al. 2011.

Snapshots 23 days apart over about 5 years.

Summary and Prospects

- "THEY" PL-relation does not exist yet.
  It depends on spectral type (C- versus O), mass-loss (colour), pulsation mode (sequence), pulsation amplitude.
  Especially when used as a distance indicator its easy to compare apples to pears.
  - Gaia will get good parallax to many (new) Miras, G-band amplitude, identify C-stars. Get $M_{\rm bol}$ lightcurve (?)
  - VMC (12 epochs over 6 months)
- Issues: LSP.
  obscuration events (R CrB like).
  metallicity effect, supposedly small, but unclear.

Summary and Prospects

- Gaia derived parallaxes of RSG and bright RG will be affected by the size of the star/enveloppe (many times the formal error)
  potentially a few 1000 objects out to $\sim$ 4 kpc.

THE END