

The Galactic Bulge AGB Population

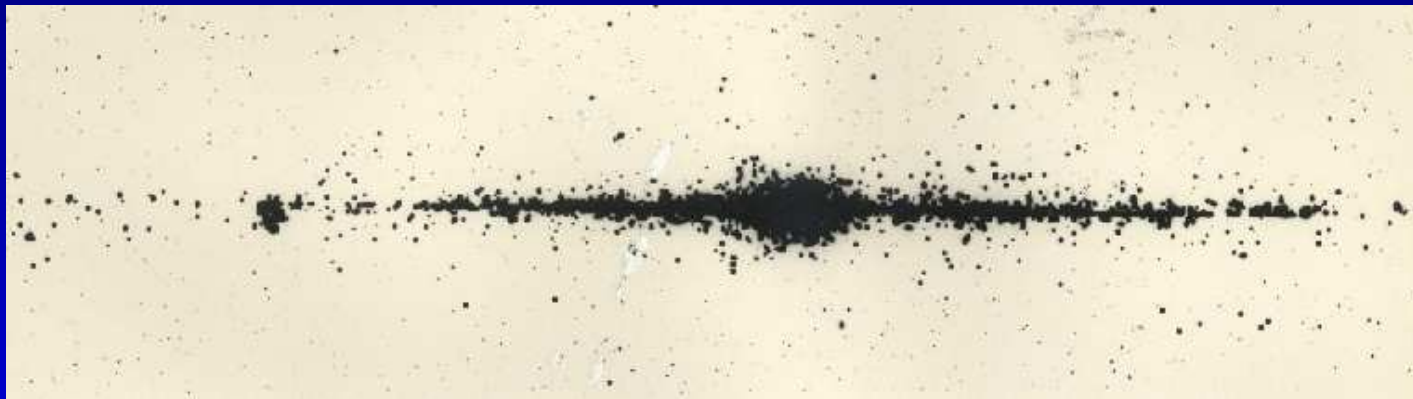
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IvS, K.U.Leuven & R.O.B.

Introduction

Some advantages of AGB stars to study the inner Galaxy:

- ★ Luminous (few thousand L_{\odot}) cool giant Stars
- ★ Much of their energy is emitted in the IR (extinction)



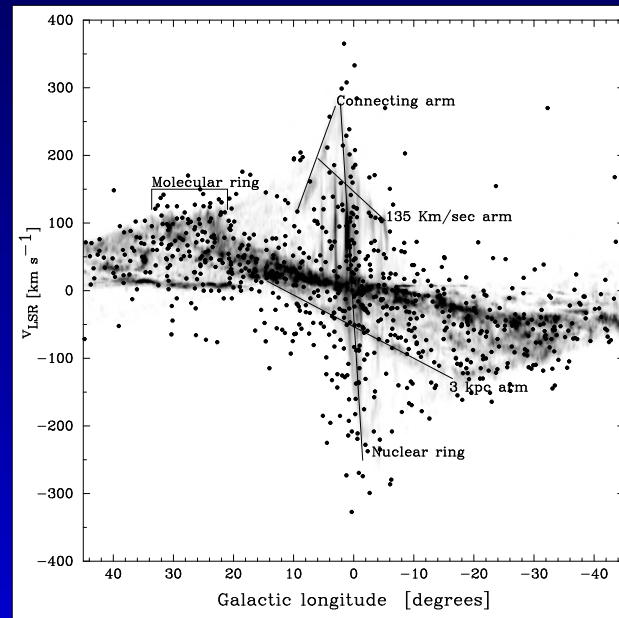
Distribution of IRAS - dusty AGB stars in galactic coordinates (Habing et al. 1985):

The first image of the MW Bulge.

Introduction (Contd.)

Some advantages of AGB stars (Contd.):

- ★ SiO- and OH maser emission, allowing to determine their velocities and so their kinematics



OH/IR stars follow a “galactic bar” with $\phi \approx 46^\circ$
(Sevenster et al. 1999)

Introduction (Contd.)

Some advantages of AGB stars (Contd.):

- ★ Large Amplitude Variability: SRV and Miras
 - helps detecting the AGB stars
 - Miras follow a P-L relation

First with *photographic plate* surveys on Baade windows, but now much more sensitive and efficient through *micro-lensing* surveys.

In the remaining of the talk we will concentrate on the **Mira** variables

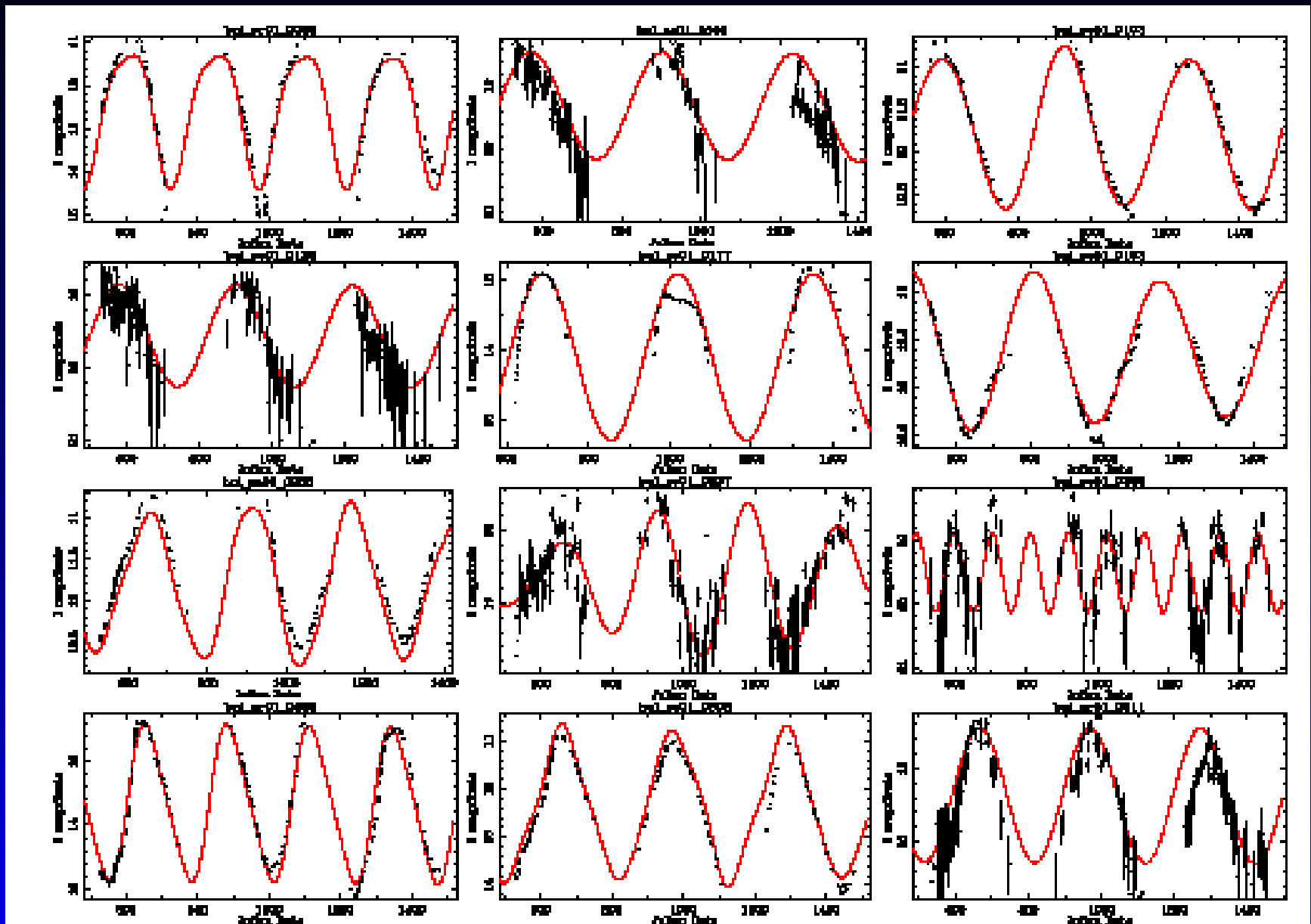
LPVs in the Galactic Bulge

- 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.

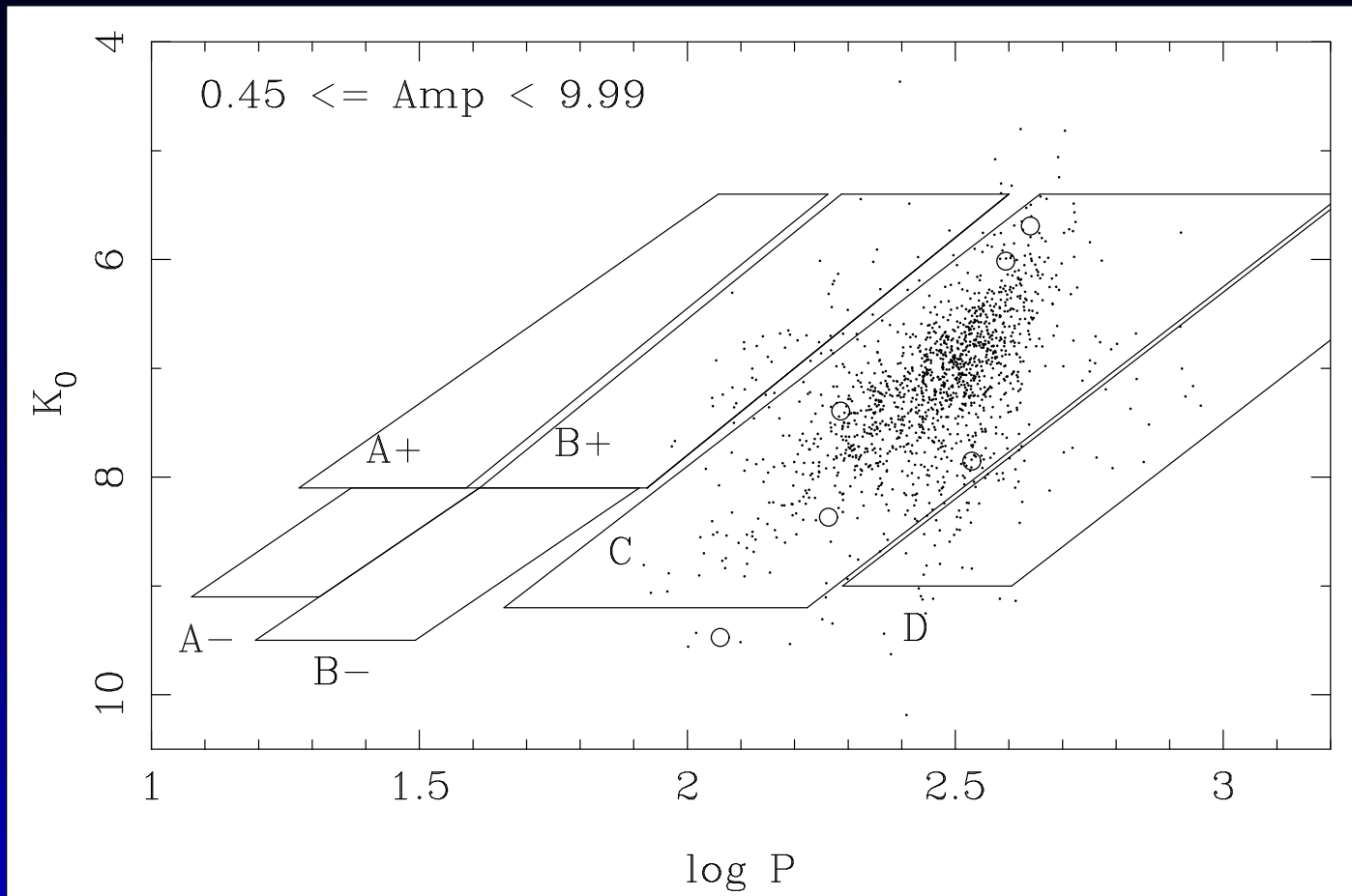
LPVs in the Galactic Bulge

Groenewegen & Blommaert (2005)

- All 49 OGLE-II fields GB
221 000 *I*-band lightcurves
- Fourier analysis + PDM at selected frequencies
(Groenewegen 2004)
- *I*-band semi-amplitude larger than 0.45 mag
- Correlation with 2MASS database on position
- Reddening from Sumi (2004),
Popowski et al. (2003)



Lightcurves of Bulge Miras



Galactic Bulge Mira K -band Period-Luminosity relation

$$m_K = (-3.37 \pm 0.09) \log P + (15.47 \pm 0.03)$$

Modelling stars in the Bulge

Binney et al. (1997) model of COBE/DIRBE data.

$$f_b = f_0 \exp(-a^2/a_m^2) / (1 + a/a_0)^\beta$$

($f_0 = 624$, $a_m = 1.9$ kpc, $a_0 = 0.10$ kpc, $\beta = 1.8$)

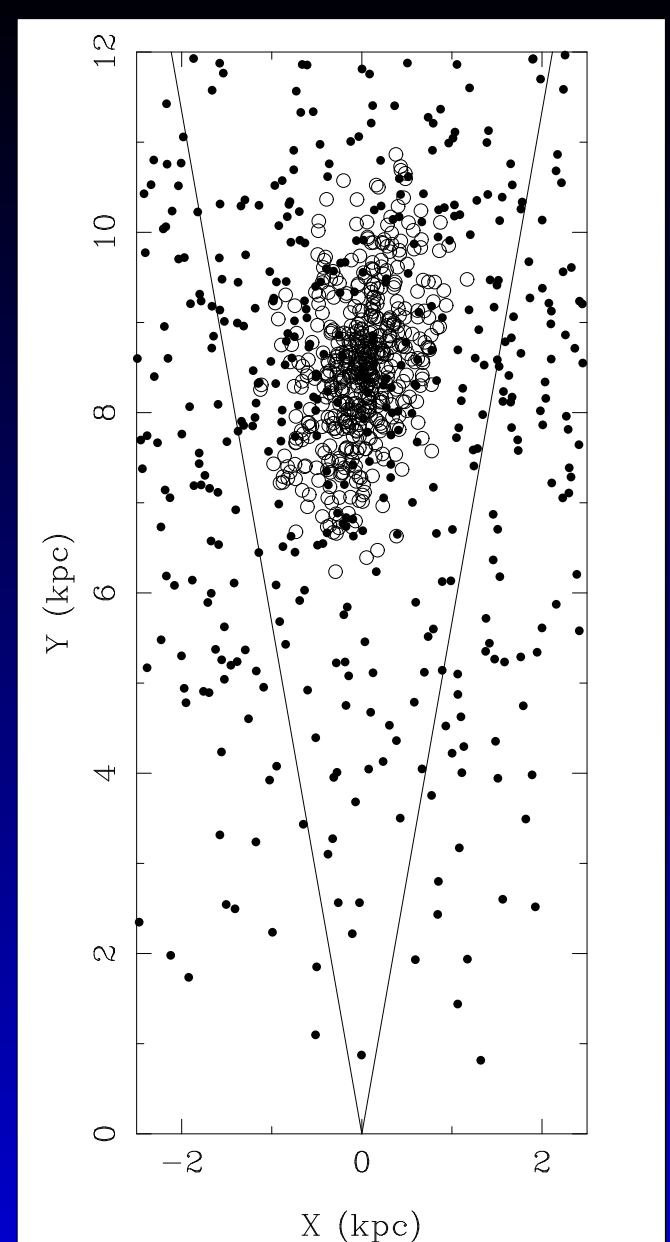
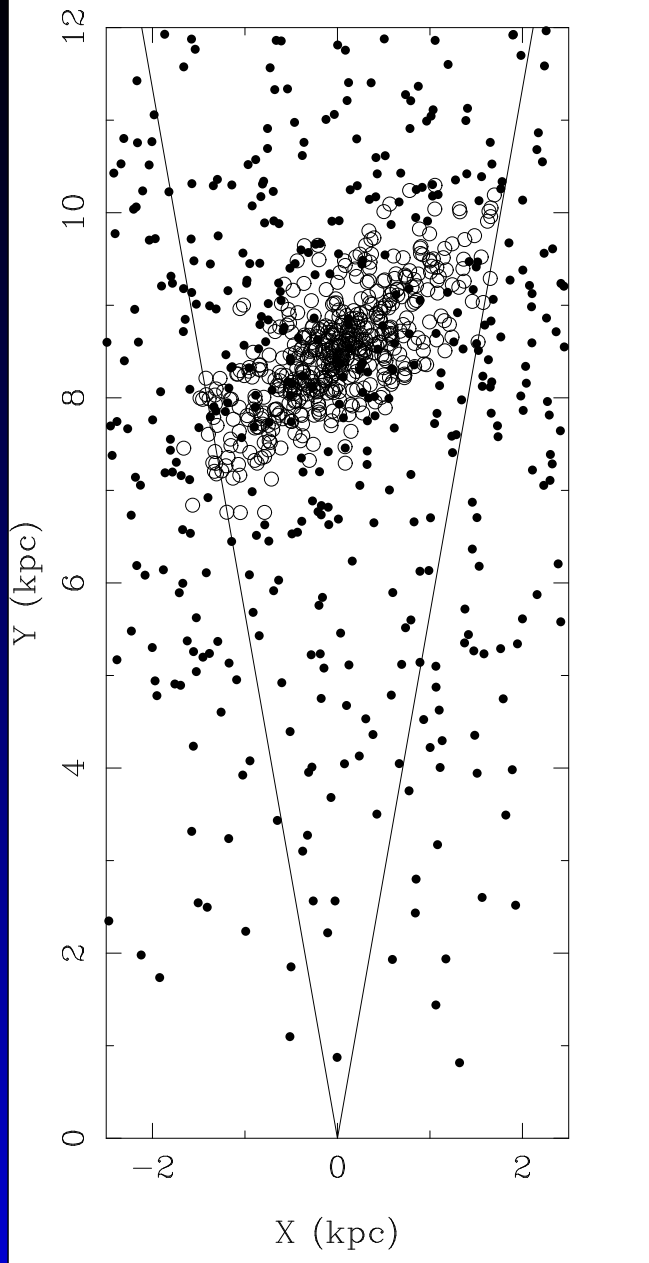
$$a = \sqrt{x^2 + (y/\eta)^2 + (z/\eta)^2}$$

with the value of $\eta = 0.5$

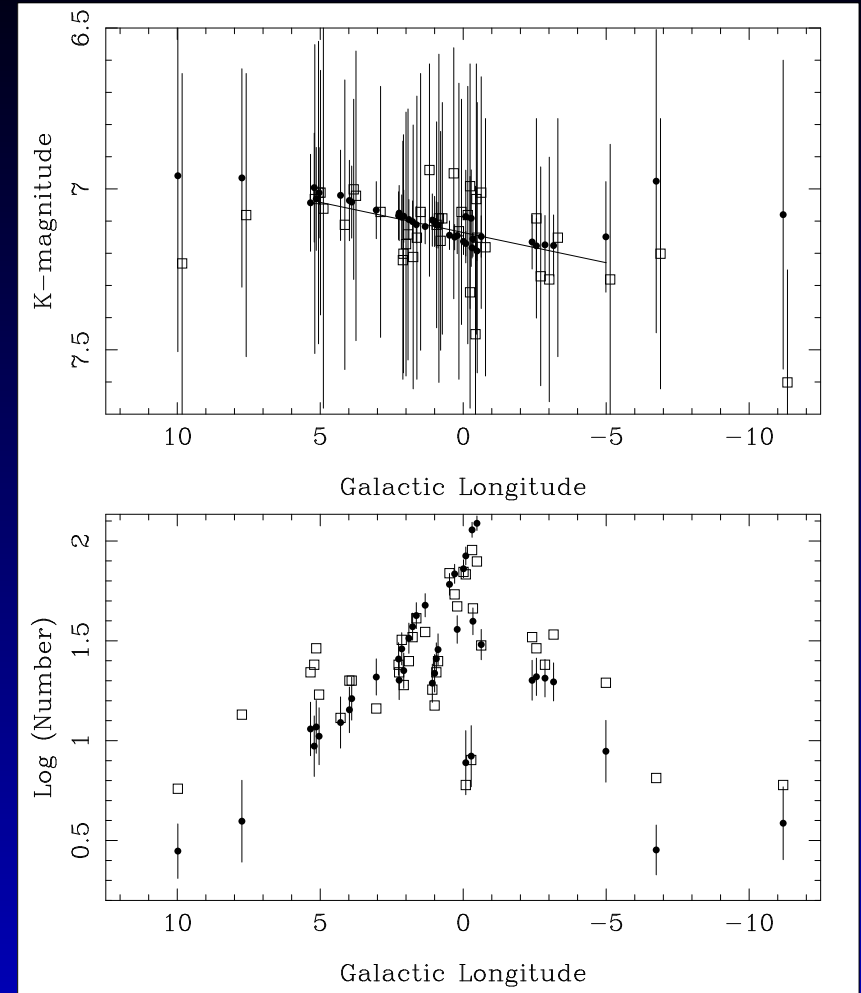
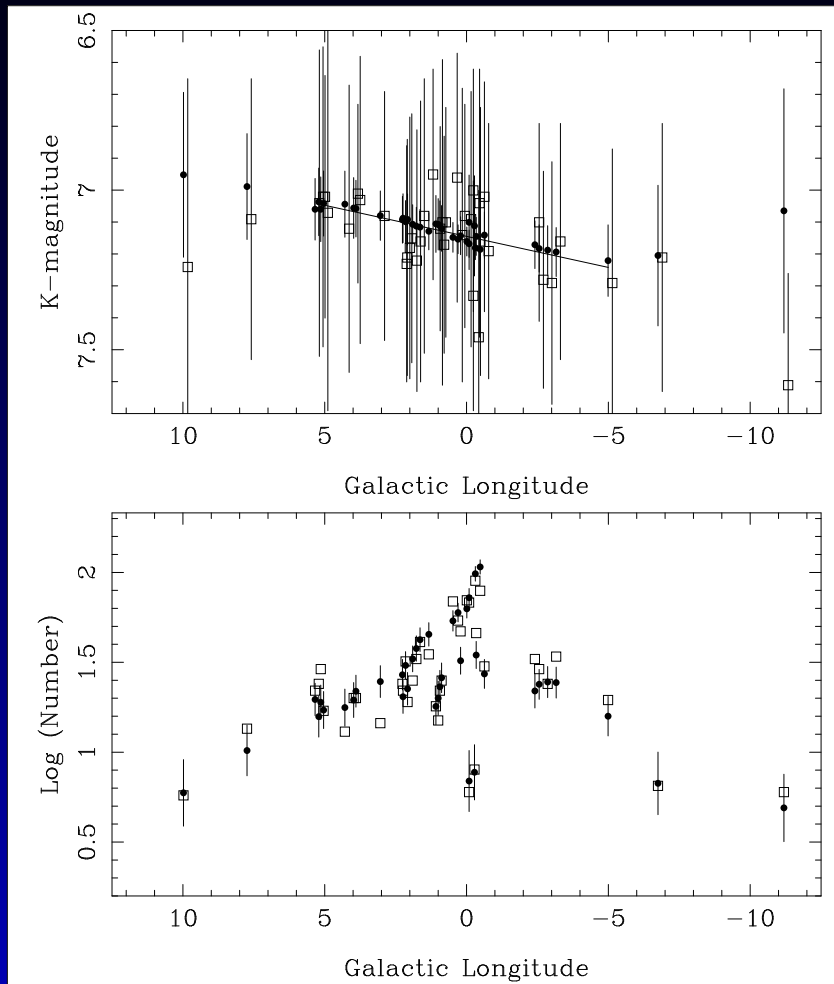
$$f_d = (\exp(-|z|/z_0) + \alpha \exp(-|z|/z_1)) \times$$

$$R_d (\exp(-r/R_d) - f_h \exp(-r/R_h))$$

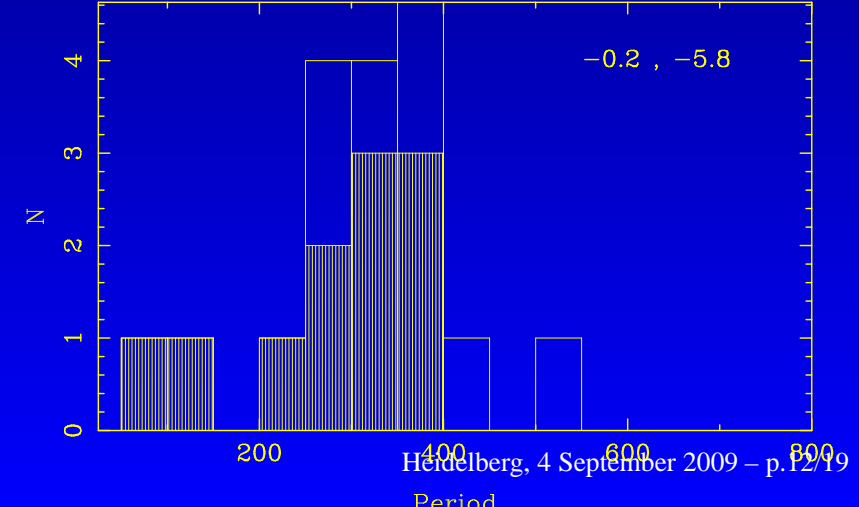
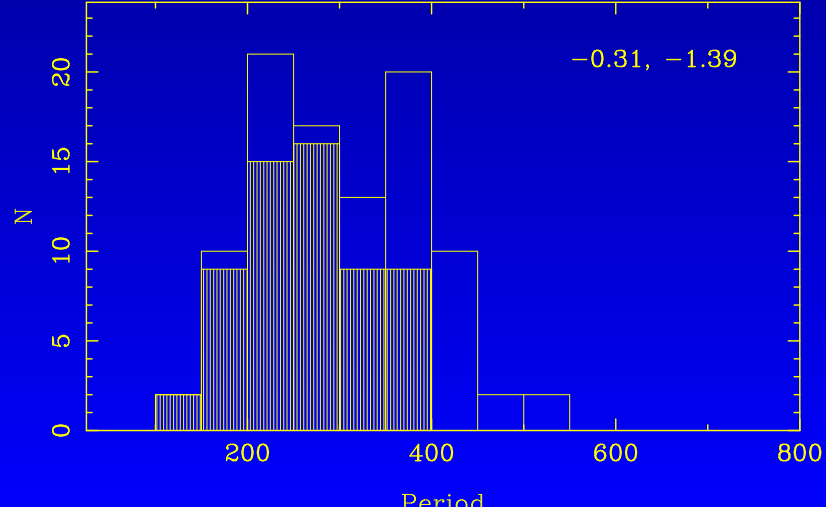
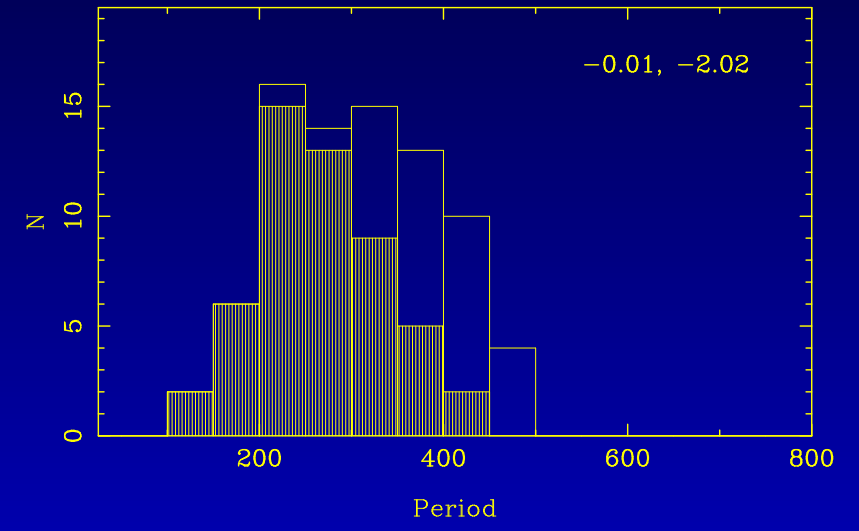
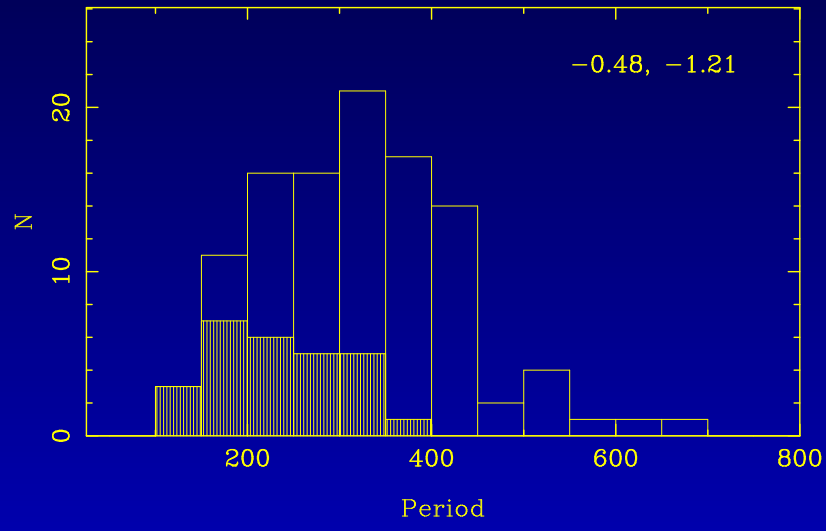
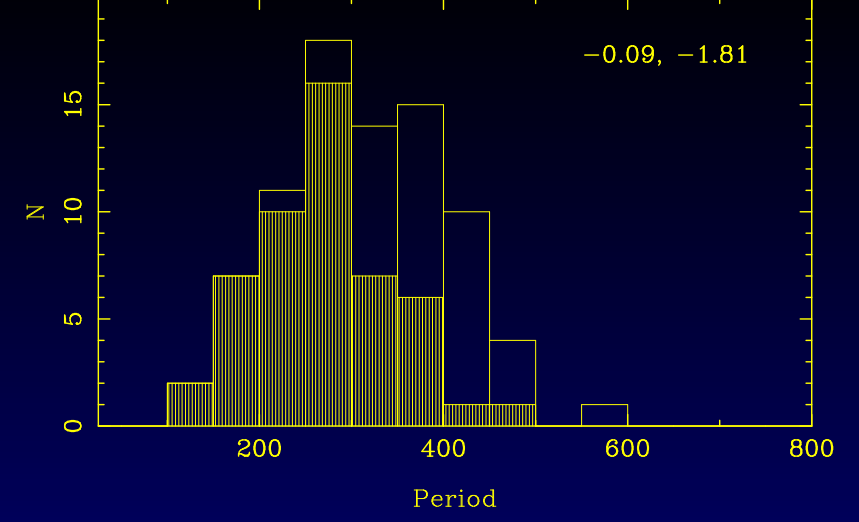
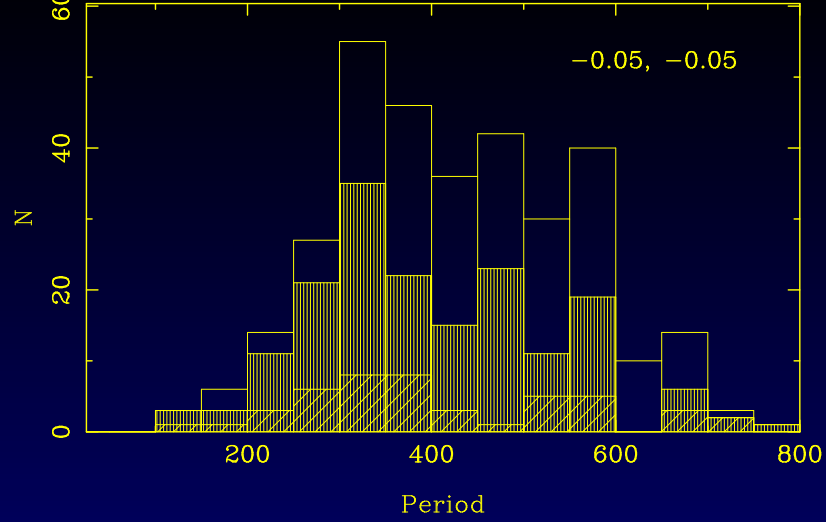
($z_0 = 210$ pc, $z_1 = 42$ pc, $\alpha = 0.27$, $R_d = 2.5$ kpc)



Top view of Bulge (o) and Disc (●) stars for viewing angles of 43 and 11 degrees.

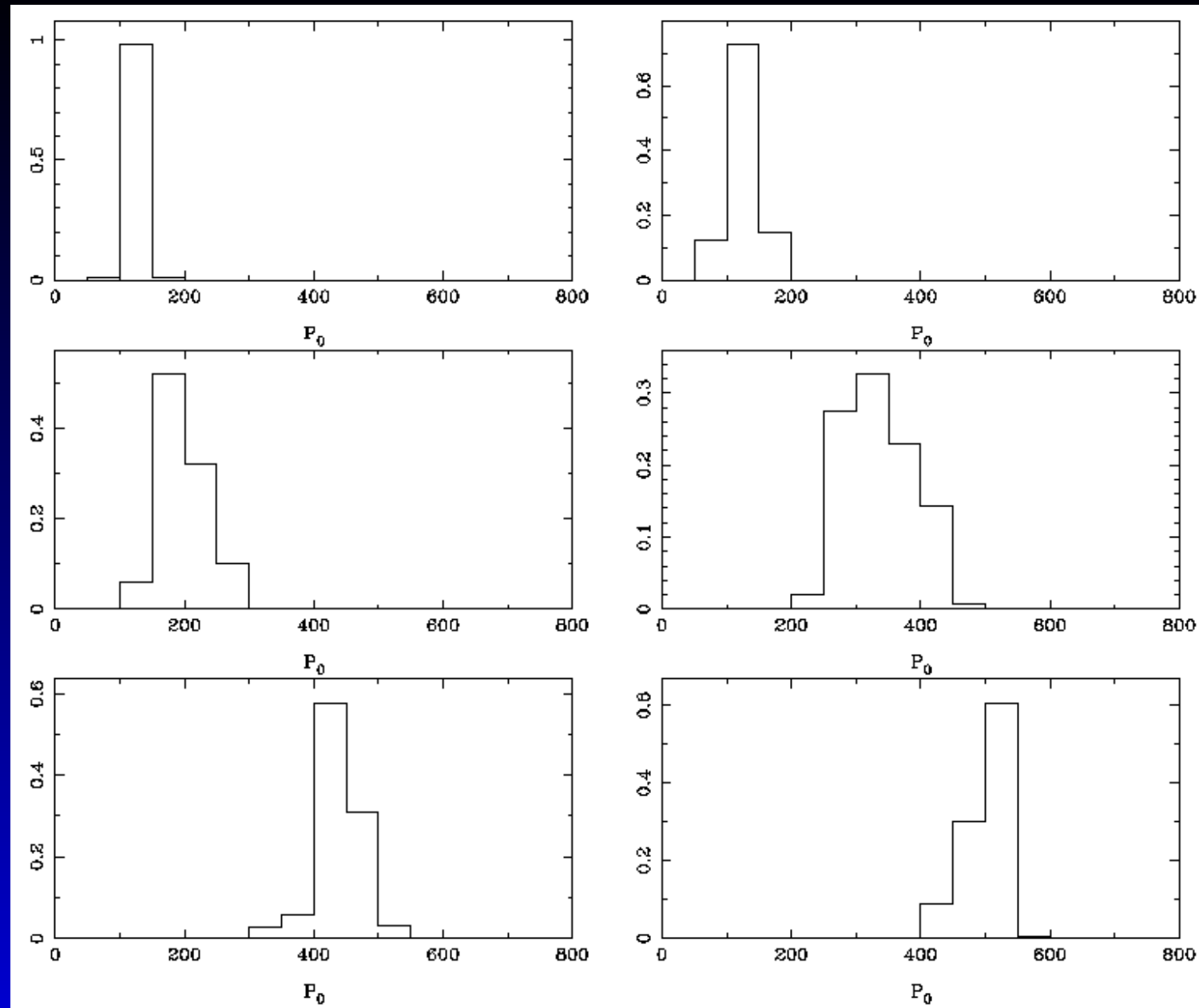


observed (\square) and modelled (\bullet) data
 Both angles fit slope versus l diagram, but only
 $\phi = 43^\circ$ fits the observed numbers



Synthetic AGB evolution

- Synthetic AGB evolution code of Wagenhuber & Groenewegen (1998)
- If a star is
 - (a) inside the observed instability strip, and
 - (b) optically visible, then
$$\log P = -2.07 + 1.94 \log R - 0.9 \log M$$
- Finetuned to give AGB and LPV lifetimes of $Z = 0.016$ stars in Vassiliadis & Wood (1993)



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)

AGB Population as function of latitude

- For $b = -1.2$ and -5.8° : 1 population with $M_i = 1.5 - 2M_\odot$ and an age between 1 - 3 Gyr
- Closer to the GC an *additional* younger population of $M_i = 2 - 3M_\odot$ and ages < 1 Gyr

The $M_i \geq 1.5M_\odot$ is also confirmed by the detection of Tc (dredge up) in AGB spectra (Uttenthaler et al. 2008)

A “young” population at low latitude is expected (Nuclear Bulge)

but at higher latitudes we should only find an old (> 10 Gyr) population (e.g. Zoccali et al. 2003, based on CMDs)

AGB Population as function of latitude

The connection of the AGB stars and the underlying old Bulge stellar population is not clear.

Indications of different populations:

- ★ Different studies show a viewing angle of $\approx 20^\circ$ and not 45° as for the AGB stars

- COBE/DIRBE brightness map
- RR Lyrae
- Red Clump stars
- CMD studies

(see Vanhollebeke et al 2009 for an overview)

- ★ Babusiaux et al (poster at the conference) show 2 populations with differences in kinematics and metallicity.

AGB Population as function of latitude

If the underlying population is of an old stellar spheroid with a short formation time, how do the AGB stars fit in? Could the Miras represent a pseudo-Bulge population?

Kormendy & Kennicutt (2004) suggest that a secondary bulge can form within an old bulge. A process that can be caused by a bar that would add “disky” material into the classical bulge.

Problem remains that in the Baade Windows no evidence is found for an intermediate age population in the NIR CMD work.

Conclusions

- Analysed the 221 000 *I*-band OGLE-II lightcurves to find 2691 Miras

$$m_K = (-3.37 \pm 0.09) \log P + (15.47 \pm 0.03)$$

- Viewing angle of the Bar: 43 ± 17 degrees
in agreement with previous work on Mira and OH/IR stars
- Period distribution at various latitudes indicate differences in population
trace population of < 1 Gyr (inner field)
to 1 - 3 Gyr (up to $b = 6^\circ$)

THE END