Data mining for reference objects to test model atmospheres of red giant stars

W. Nowotny[1], B. Aringer[1], K. Eriksson[2], H.-P. Gail[3], L. Girardi[4], S. Höfner[2], P. Marigo[5], A. Mayer[1]

[1] Department of Astrophysics, University of Vienna (Austria), [2] Department of Physics and Astronomy, Uppsala University (Sweden),
[3] Institute for Theoretical Astrophysics, University of Heidelberg (Germany), [4] INAF – Padova Astronomical Observatory (Italy),
[5] Department of Astronomy, University of Padova (Italy)

1. General approach

- based on different types of models for the outer layers of evolved red giants detailed radiative transfer is solved
- outcome = synthetic spectra and calibrated synthetic photometry in standard Johnson-Cousins-Glass broad-band filters (cf. Girardi et al. 2002, Aringer et al. 2009, Nowotny et al. 2011)
- comparison of modelling results with various observational data from the visual to the near-IR with two major aims:
  - testing if models describe the observed targets adequately
  - interpreting objects and their host stellar systems by applying the models

2. Survey data compiled from various sources

observational data from publicly available (mostly) photometric surveys;
post-processing (dereddening, distance moduli, filter conversions, etc.) applied;

- **Galactic Bulge** population: → Figs.1+2c
  field of $\Delta\alpha \times \Delta\delta = 0.5° \times 1°$ towards Baade's window;
  single-epoch *JHK* photometry from 2MASS point-source catalog (Cutri et al. 2003);
  mean *VI* magnitudes from OGLE averaged over time-series (Udalski et al. 2002);
  O($10^4 \ldots 10^5$) objects
- sample of **Galactic Bulge Miras** from Groenewegen et al. (2005): → Fig.1
  1619 M-type Miras in the bulge of the Milky Way;
  identified by analysing photometric variations (*I*-band) provided by OGLE-II survey;
  cross-correlation with 2MASS and OGLE photometric maps → mean *VIJHK* mags
- sample of **galactic C-type Miras** from Whitelock et al. (2006): → Fig.2
  time-series JHKL photometry for a sample of field LPVs → lightcurves, periods *P*, amplitudes ΔK
  mean magnitudes dereddened for interstellar extinction;
  estimates for other quanitites as e.g. mass-loss rates, m_{bol}, distance moduli (m–M)
- variable stars in the LMC from Ita et al. (2004): → Fig.2d
  period estimates based on analysed OGLE lightcurves and *JHK* photometry
- several others (AAVSO lightcurves, ISO spectra, Spitzer, etc.) → e.g. Fig.3

3. Hydrostatic model atmospheres

- grid of hydrostatic (i.e. dust-free) COMARCS model atmospheres for O-rich (Aringer et al., in prep.) and C-rich chemistry (Aringer et al. 2009)
- combined with evolutionary tracks from synthetic evolutionary models (Marigo et al. 2007, 2008);
  example for a typical star ($1M_\odot$, $Z_\odot$) along the **RGB** and **AGB** → Fig.1;
  various other tracks for α-enhanced bulge abundances (Bensby et al. 2011) calculated, interpolation scheme about to be implemented
- aim: interpreting characteristics of the Galactic Bulge by using synthetic CMDs simulated with the population synthesis code TRILEGAL (Girardi et al. 2005)

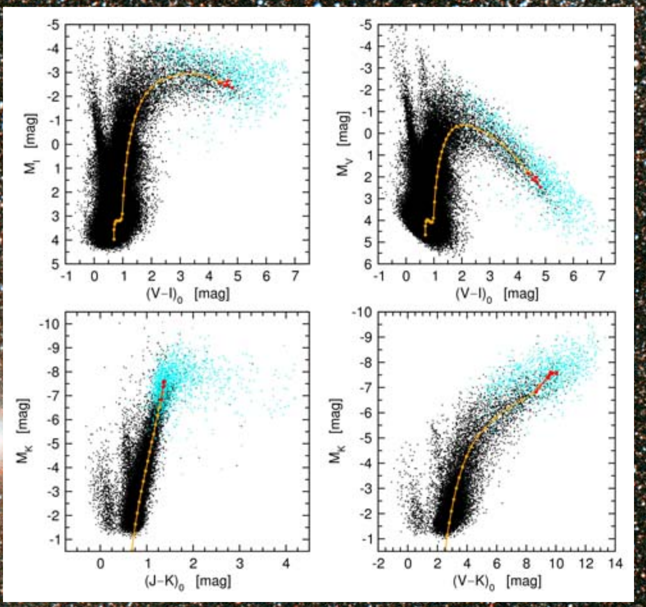

Fig. 1: Colour-magnitude diagrams of the **Galactic Bulge** (Baade's window) for different filter combinations based on 2MASS and OGLE data. Overplotted are the **Miras** identified by Groenewegen et al. (2005) across the bulge as well as the evolutionary track for a solar-like star (colour-coded are **RGB** and **AGB**).

4. Dynamic model atmospheres

- models simulating the scenario of pulsation-enhanced **dust-driven winds** for mass-losing long-period variables (cf. Höfner et al. 2003, Mattsson et al. 2010, Nowotny et al. 2010, 2011)
- consistent description from the deep, dust-free photosphere (dominated by the pulsation of the stellar interior) out to the dust-forming layers and beyond to the stellar wind region (characterised by a cool, steady outflow containig dust grains)
- mainly for LPVs with C-rich atmospheric chemistry (driving mechanism evident); [models for O-rich objects recently investigated by Höfner 2008, Bladh et al. 2012]
- Nowotny et al. (A&A, submitted): → Fig.2
  aim = reproducing the diverse photometric properties of C-rich Miras, esp. of the comprehensive sample of well-characterised objects from Whitelock et al. (2006)
- set of five representative models with varying parameters (L, T_{eff}, C/O, P, Δm_{bol}, mass loss rate, …); comparison of mean photometry (i.e. average over light cycles)
- models are able to reproduce the observable properties (absolute magnitudes, NIR colour indices, photometric amplitudes ΔK, mass-loss rates, etc.) and allow to **trace the observed sequence of C-type Miras** with increasing mass-loss being the most significant effect along the sequence (circumstellar reddening)

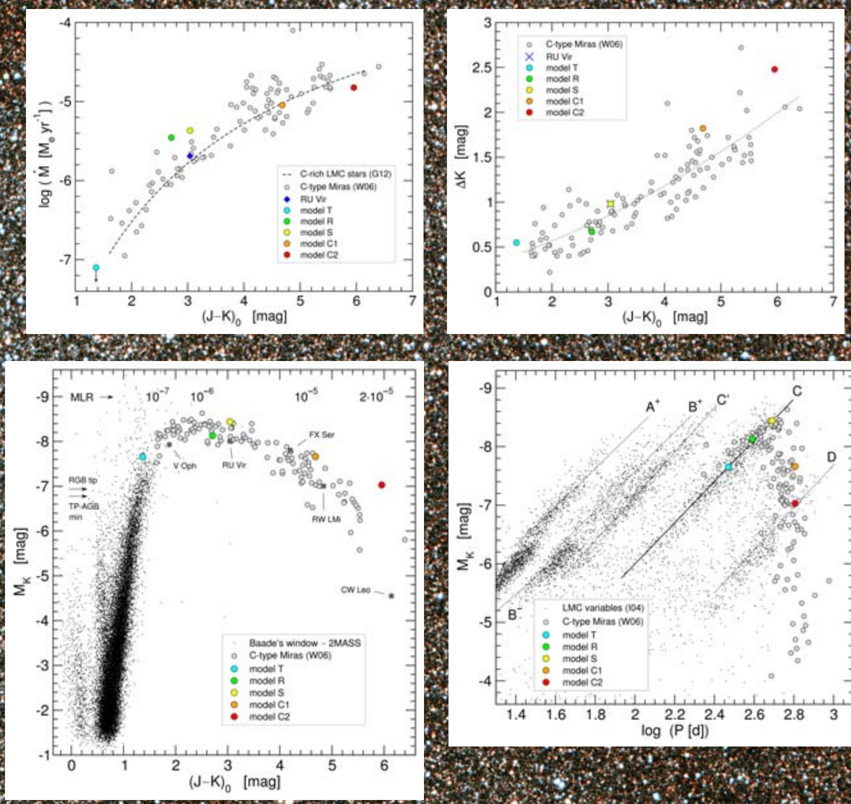

Fig. 2: Set of C-rich dynamical models compared with observational data adopted from the literature, mainly to the sample of field C-type Miras from Whitelock et al. (2006; W06). The empirical relation between MLR and (J–K) adopted from Gullieuszik et al. (2012; G12) is shown in the upper left panel. The K-log(P) diagram contains LMC variables from Ita et al. (2004; I04) and the known P-L-relations for LPVs as fitted by the same authors. Both were shifted to an absolute scale by assuming a distance modulus of $(m–M)=18.5^{mag}$ for the LMC.

5. Stationary wind models

- models for the dusty outflows of AGB stars (beyond $\approx 2R_*$) as described in Ferrarotti & Gail (2006), incl. recent improvements of the code (Gail et al., in prep.)
- very **detailed mineralogy** including various relevant dust species: olivines $(Mg,Fe)_2SiO_4$, pyroxenes $(Mg,Fe)SiO_3$, quartz SiO_2, iron, magnesio-wustite $(Mg,Fe)O$, alumina Al_2O_3, spinel $MgAl_2O_4$, amorphous C, SiC, MgS, etc.
- COMARCS model atmospheres combined with wind models to simulate the spectra of mass-losing AGB stars, including the contributions from the photospheres as well as the circumstellar dust envelopes;
  R Aqr (MLR ≈ $7.10^{-7} M_\odot$/yr) as an example (Mayer et al., A&A, accepted) → Fig.3

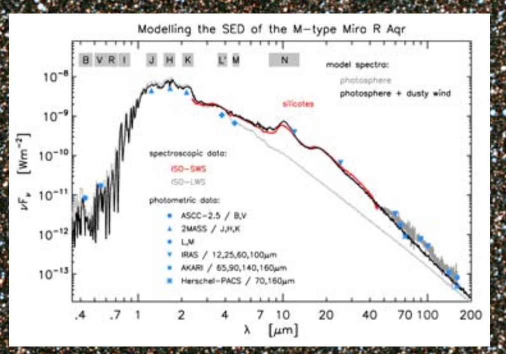

Fig. 3: Spectral energy distribution of the Mira R Aqr as determined by survey data adopted from different sources (see legend). Overplotted is the synthetic spectrum reproducing the global SED as well as the characteristic emission features at 10 and 18μm due to silicate dust grains in the stellar wind.

References:
Aringer et al. 2009, A&A, 503, 913
Bladh et al., A&A, 2012, in press (arXiv 1209.2112)
Bensby et al. 2011, A&A, 533, A134
Cutri et al. 2003, VizieR Online Data Catalog, II/246
Ferrarotti & Gail, 2006, A&A, 447, 553
Girardi et al. 2002, A&A, 391, 195
Girardi et al. 2005, A&A, 436, 895
Groenewegen et al. 2005, A&A, 443, 143
Gullieuszik et al. 2012, A&A, 537, A105
Höfner et al. 2003, A&A, 399, 589
Höfner 2008, A&A, 491, L1
Ita et al. 2004, MNRAS, 347, 720
Marigo et al. 2007, A&A, 469, 239
Marigo et al. 2008, A&A, 482, 883
Mattsson et al. 2010, A&A, 509, A14
Nowotny et al. 2010, A&A, 514, A35
Nowotny et al. 2011, A&A, 529, A129
Udalski et al. 2002, Acta Astron., 52, 217
Whitelock et al. 2006, MNRAS, 369, 751

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Baade's Window to the Core of the Milky Way