# The most accurate mid-infrared Period-Luminosity Relations for Miras

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## Abstract

Pulsating stars are excellent distance indicators in the nearby Universe, because they obey Period-Luminosity Relations (PLRs). We used densely covered, 20-years-long I-band light curves for 1663 Miras in the Large Magellanic Cloud (LMC), collected by The Optical Gravitational Lensing Experiment (OGLE), to create I-band light curve templates. Using these templates and mid-infrared observations from the Spitzer and WISE space telescopes (spanning a wavelength range from 3.4 to 22 microns), we measure the mean magnitudes for almost the full sample of Miras. We then construct PLRs in four Spitzer and four WISE bands. These PLRs allow measurements of the distance to individual Miras at the level of ~5%, and could be used for measuring distances in the Milky Way.

## About Miras

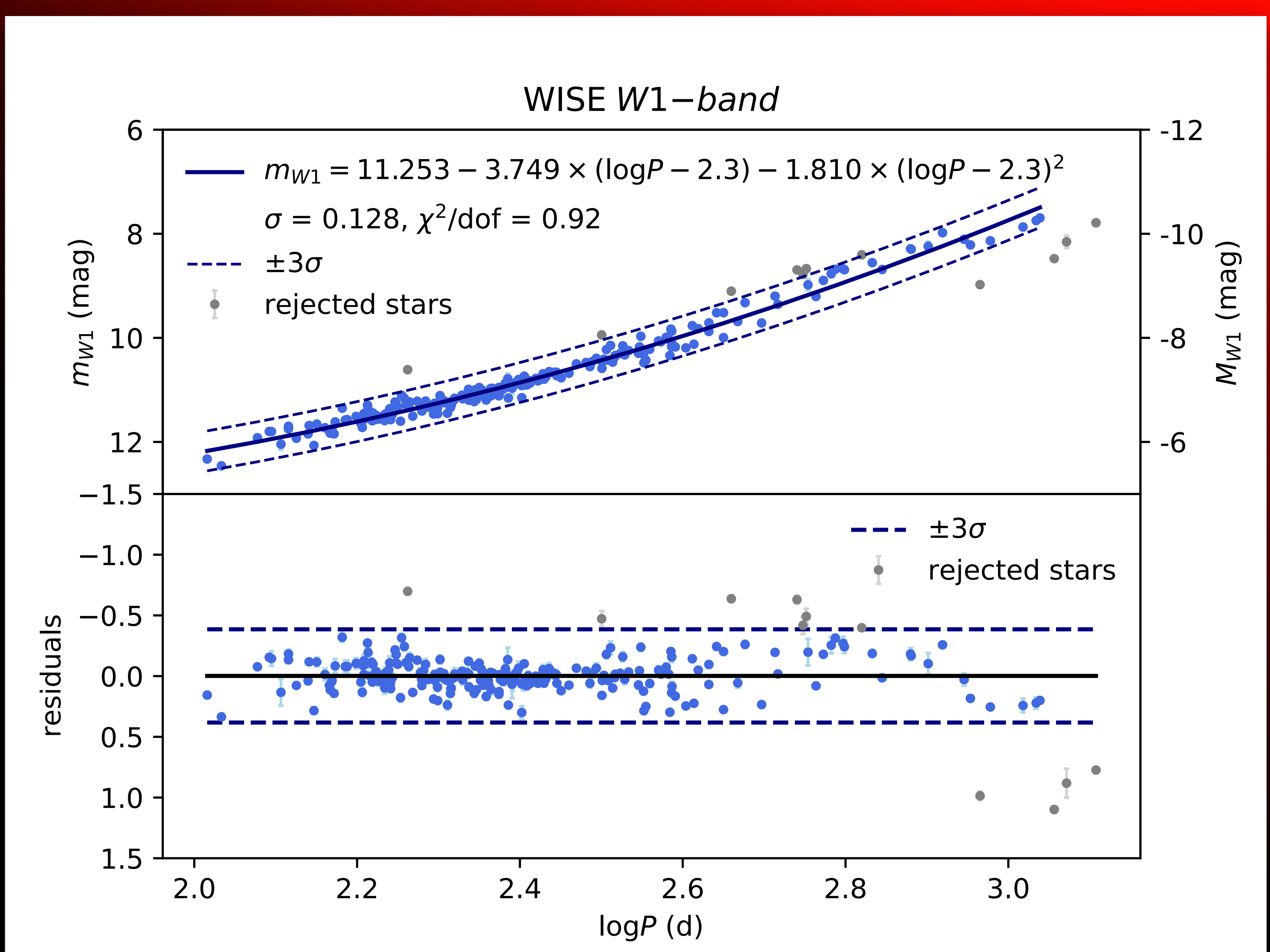
Mira variables are fundamental-mode pulsators with periods ranging from ~100 days to over 1000 days. They belong to the class of late-type, low- or intermediate-mass pulsating red giants also known as Long Period Variables (LPVs). Miras are Asymptotic Giant Branch (AGB) tracers of old- and intermediate-age populations. Like other AGB stars, they can be divided into oxygen-rich (O-rich) and carbon-rich (C-rich) giants, depending on their surface composition. Miras, thanks to their large brightness variations, can be easily found in the Milky Way and other Local Group galaxies, and they are an extensively studied subclass of LPVs.

## Why mid-infrared?

PLRs for Miras are tighter and better defined at infrared wavelengths than in optical bands, as Mira PLRs are generally flat in optical, but also blurred by stronger effects of the interstellar and circumstellar extinction, and hence harder to work with. Therefore, in this project we used observations from Spitzer (3.6-8.0 microns) and WISE (3.4-22 microns) space telescopes. In contrast to the densely covered I-band OGLE light curves, mid-infrared light curves are sparsely sampled (up to several epochs per light curve in WISE and up to two epochs per light curve in Spitzer).

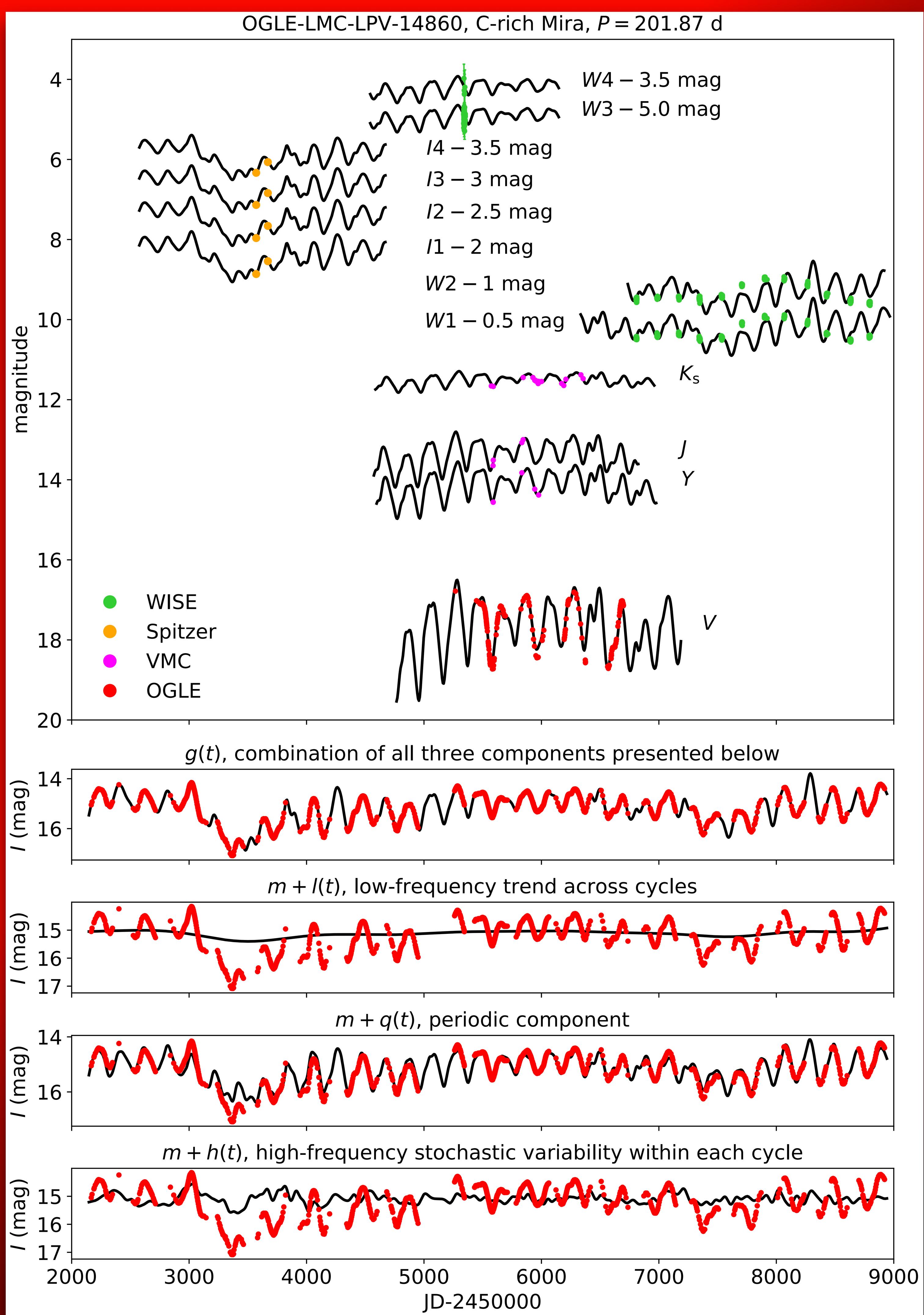
## PLRs for O-rich and C-rich Miras

Using the linear and quadratic PLRs models, and sigma-clipping procedure we performed fits to the datasets using the weighted least squares method. We iteratively fitted the linear model to the O-rich and C-rich Miras, and the quadratic model to the O-rich Miras only. We fitted separate models for each WISE and Spitzer bands. In each iteration, we rejected points deviating by more than 3$\sigma$. We calibrated the Mira PLRs using the most accurate distance measurement to the LMC. The PLRs obtained in this work can be used to measure distances to the Mira-type stars in the Milky Way and nearby galaxies. The distance to an individual Mira star can be measured with the accuracy at the level of 5% and 12% for the O-rich and C-rich Mira, respectively. Below we present one example of PLR, for O-rich Miras. Blue points present measured mean magnitudes in WISE W1-band, while gray points present rejected measurements. By solid line we marked best-fitted model, while dashed lines present 3$\sigma$ range.




## Measuring mid-infrared mean magnitudes

To measure mean magnitudes from sparsely sampled variable mid-infrared light curves, we first modeled the high-cadence OGLE I-band data with the semi-parametric Gaussian process regression (GPR) model, which contains three components (l(t), q(t) and h(t), presented in the Figure below). We then fitted the GPR templates by modifying their amplitude, shifting in time and magnitude to match the mid-IR light curves. Having the best parameters for the variability amplitude ratio, phase-shift, and magnitude shift, we transformed the light curve template to the mid-IR datasets of interest. In the next step, we used transformed templates to measure the mean magnitude in the WISE and Spitzer bands. Each template light curve was transformed to the flux scale, fitted with a third-order truncated Fourier series, integrated to determine the mean brightness, and finally transformed back to the magnitude scale. An example of a C-rich Mira light curve in several optical/near-/mid-infrared bands with fitted models is presented below.

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