RR Lyrae Stars in the Far Ultraviolet:
GALEX Observations Compared with Theoretical Predictions

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The GALEX Mission

GALEX is a NASA Small Explorer satellite, launched in April 2003, and is currently surveying the sky at UV wavelengths from 1350-2800A.

- *Several imaging surveys are in progress:*
  - *AIS: All Sky Survey, 40000 degrees^2 to AB=20.5 mag*
  - *MIS: Medium Imaging Survey, 1,000 degrees^2 to AB=23 mag*
  - *DIS: Deep Imaging Survey, 80 degrees^2 to AB=25 mag*
  - *NGS: Nearby Galaxy Survey, 240 degrees^2 to AB=23 mag*
- *Photon-counting detectors enable high time-resolution (<0.01s) UV photometric observations.*
- *Independent detectors simultaneously observe at FUV (1350-1750A) and NUV (1750-2800A)*
- *Public releases of GALEX data are available at* `galex.stsci.edu`, *at the Multi-Mission Archive at the Space Telescope Science Institute (MAST).*

Standard Candles in the Ultraviolet

- RR Lyrae stars in crowded fields in the cores of globular clusters and in the Magellanic Clouds may be easier to detect in the UV than in the visible

- RR Lyraes are far less luminous in the FUV that in the visible, making them hard to detect in distant galaxies

GALEX RR Lyrae Observations

- The wide field of view (1.2 degrees), high sensitivity (AB~23 mag in 1500 s), and low background enable GALEX to serendipitously detect many variable and transient sources during its surveys

- In the MIS and DIS surveys, GALEX makes repeat visits to star fields: this has proven ideal for producing high-quality RR-Lyrae light curves at FUV and NUV wavelengths

- We illustrate GALEX light curves for six RR Lyrae ab*-type variables that have many observations well distributed in phase (central panels).*

- RR Lyraes vary by 4-6 magnitudes in FUV, and by 2-3 mag in NUV, far more than the ~1 mag variations at visible wavelengths

The Pulsation Cycle

- All ab*-type RR Lyraes have a minimum atmospheric temperature of ~6000K, occurring between phases .5 and .85*

- At maximum light, the peak temperature can reach anywhere from 7000K to 7800K, depending on the mass of the star

- The star's radius reaches a minimum at phase 0.85, just before the rapid brightness rise to maximum, which accounts for the slight dip at this phase

- Surface gravity varies as a function of the star's radius, and also due to radial acceleration during expansion and contraction in the pulsation cycle

Kurucz Model Atmospheres in the FUV

- Kurucz (2003) has computed ultraviolet stellar spectra over a wide range of metallicities, temperatures, and surface gravities, using the improved opacities of Iglesias, et al. (1996).

- In the GALEX FUV band (1350-1800A), Kurucz predicted fluxes are highly sensitive to metallicity and temperature in the 6000-7500K range, but far less sensitive to surface gravity (log g, cgs units).

- This contrasts with longer wavelengths (4000-10000A), where the predicted RR Lyrae flux is largely insensitive to metallicity.

- We explore a range of temperature and metallicity to fit the observed GALEX and visible light curves

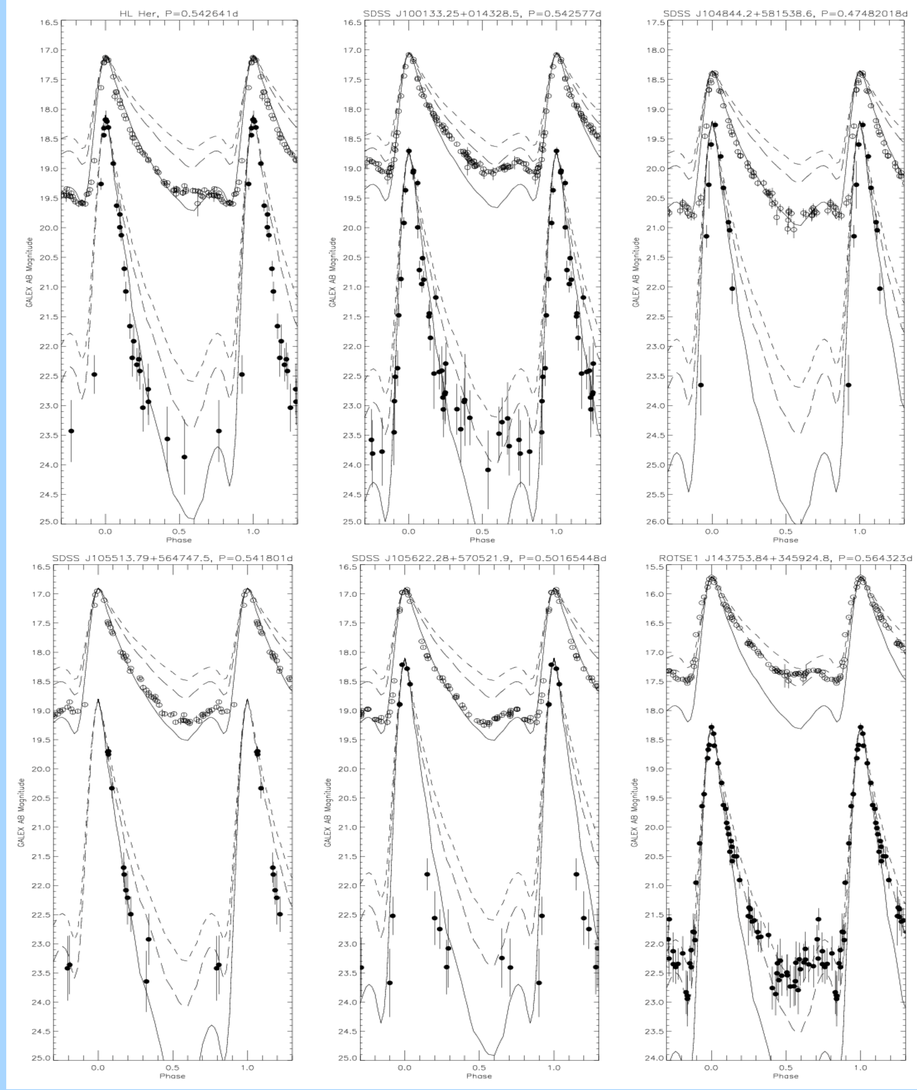


Figure 1. RR Lyrae light curves in NUV (1800-2800A, open circles) and FUV (1350-1800A, filled circles), with one sigma error bars. Amplitudes are ~2.5 mag in NUV and 5-6 mag in FUV. Overlayed are Kurucz model atmosphere light curves (see below) for **[Fe/H]=0.0** *(short dash),* **[Fe/H]=-1.0** *(long dash) and* **[Fe/H]=-1.75** *(solid line).*

Fitting Models to the GALEX Light Curves

- We begin with a temperature variation of 5900-7300K, deduced from visible photometry of `ROTSE-I J143753.84+345924.8` *(lower right in Fig. 1) by Wheatley et al. (2005).*

- Metallicities ranging from **[Fe/H]=0.0 to -1.75** *are explored to find the best fit to the ultraviolet light curves*

- Lower metallicities produce dramatically larger amplitudes in the FUV light curves

- The observed 5-6 magnitude FUV variations are consistent with metallicites of -1.0 to -1.5

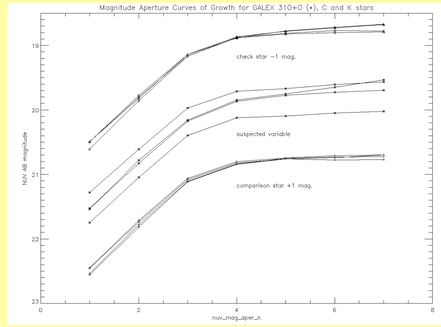
- Model light curves are poorly constrained by UV data alone

- Our continuing Lick Observatory photometry program will pinpoint the temperature variations of these stars, allowing more accurate UV-derived metallicities

Reference: Wheatley, J.M. et al. 2005, **Large-Amplitude Ultraviolet Variations in the RR Lyrae Star ROTSE-I J143753.84+345924.8.** *Astrophysical Journal, Volume 619, Issue 1, pp. L123-L126.*

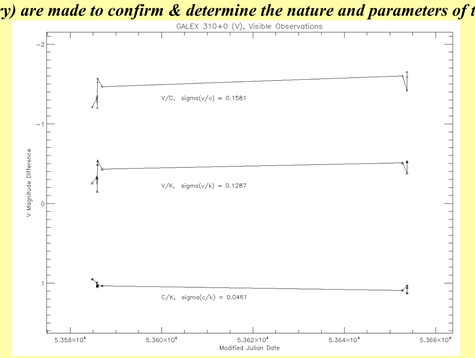
GALEX Aperture Curves of Growth

Several stars with a small range of NUV or FUV magnitudes in GALEX fields are examined to produce aperture growth curves.
Curves with a small variance are compared to curves for other stars within a selected magnitude range in different exposures to produce a time series to check for variability.



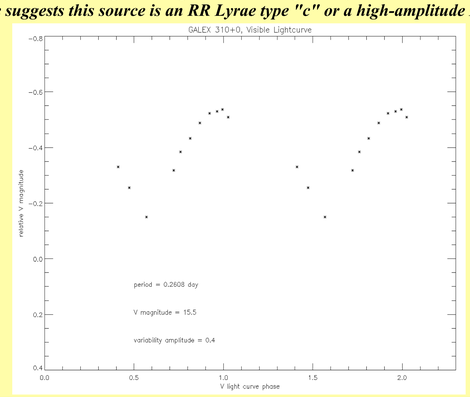
Visible Observations of GALEX Variables

If only a few GALEX observations exist, as here, visible observations (at the Lick Observatory) are made to confirm & determine the nature and parameters of the variability.



From Visible Observations, A Light Curve Emerges

In this case, a light curve emerged through a "least string" analysis of the visible Lick data. The light curve suggests this source is an RR Lyrae type "c" or a high-amplitude Delta Scuti star.



Conclusions

- *GALEX FUV light curves with amplitudes of 5-6 magnitudes are consistent with Kurucz model atmosphere predictions.*
- *Ongoing optical V-band photometry at the Lick Observatory will better constrain the metallicities derived from GALEX data*
- *New UV variable star candidates can be discovered in GALEX observations by a comparative curve-of-growth photometric analysis*
- *Future GALEX observations may produce FUV and NUV light curves of other kinds of pulsating variables, such as δ Scuti stars*