An old Friend, in a new light
The Story of RR Lyrae
$m_V = 7.06 - 8.12$
The variability of RR Lyrae ($\alpha = 19^{h} 22^{m}$; $\delta = +42^\circ 6$) was discovered by Mrs. Fleming on a multiple-exposure photograph taken July 13, 1899. From 1899 until the beginning of 1902 the star was observed by Wendell with the photometers attached to the East Equatorial of the Harvard College Observatory, a total of 241 observations being secured. From these observations a period of 0.5668 day and a range in brightness of 0.83 magnitude were deduced. In the Harvard Second Catalogue of Variable Stars, RR Lyrae is assigned to Class IV, of the Harvard Classification, which includes all short-period variables whose light changes are not due to eclipses. But Class IV stars, although possessing similar characteristics of variation in general, fall into three groups according

In a letter to Director Campbell, Hertzsprung of Potsdam called attention to the fact that RR Lyrae is the brightest Cluster Variable so far known. Its light ranges between the seventh and eighth magnitudes, thus enabling it to be observed with a low-dispersion spectrograph attached to the 36-inch refractor. As a result of his own observations Hertzsprung found a period of 0.56682 day, and that a photographic maximum occurred at J. D. 2418919.448.

During the latter half of 1912, photometric observations of RR Lyrae were made at Mount Hamilton, and from them a new light curve was drawn. The observations upon which the curve is based, are as in Table I. With one exception, all the observations of August 20 and September 13 were made by Dr. S. D.
Tucker 1913, Lick Observatory Bulletin, No. 7
Data from Kolenberg et al. 2006
The Blazhko Effect

(Blazhko 1907)

Blazhko Period \( P_B \)

Radial Pulsation Period \( P_0 \)
The Blazhko Effect

\[ \Delta = \omega_e - \omega_b \]

Closely Spaced Resonance

Convective Cycles

Oblique Rotator

Nonradial Modes

Interaction
A Spectroscopic Study of the Blazhko Effect in RR Lyrae
Katrien Kolenberg
RR Lyraes in the Kepler field

~ 50 RR Lyrae stars known
RR Lyrae star

Long Cadence versus Short Cadence

~ 30 min

~ 1 min
Typical Kepler Long Cadence Data

Kolenberg et al. (2010)
Benkő et al. (2010)
RR Lyr in Kepler field
THANKS, Steve and Martin!

Custom aperture by Steve Bryson (NASA Ames)
Why do some stars do it and others don’t?
Repeating cycles
Blazhko modulation
Period Doubling
FIRST KEPLER RESULTS ON RR LYRAE STARS

Manifestations of period doubling:
alternating cycles
half-integer frequencies \((1/2 \, f_0, \, 3/2 \, f_0, \, 5/2 \, f_0, \ldots)\)

Kolenberg et al. (2010)
Szabó et al. (2010), Kolláth et al. (2011)

Only Blazhko stars show period doubling ...

Buchler & Kolláth (2011)
TAKING THE "PULSE" OF STARS

Subgiant
KIC 11026764

Red giant
KIC 9300159

Blue giant
RR Lyrae
Why was period doubling not seen before?
Why was period doubling not seen before?

“terrestrial exclusion principle”
Several other interesting new types of behavior uncovered.
Ground-based follow-up

For all of the known RR Lyrae stars in the Kepler field:

\textbf{(U)BVRI} multicolor photometry
- 1-m, 41-cm, Lulin Observatory, Taiwan
- 81-cm, Tenagra Observatory, Arizona, USA
- 1.8-m and 15-cm, BOAO, Korea
- 61-cm, SOAO, Korea
- 1-m, LOAO, Arizona, USA

high-resolution spectroscopy
- 3.6-m CFHT, Hawaii, USA
- 10-m Keck, Hawaii, USA
- 2.7-m, McDonald Observatory, USA
Ground-based follow-up

For all of the known RR Lyrae stars in the Kepler field:
(U)BVRI multicolor photometry and high-resolution spectroscopy
Nemec et al. 2013

CFHT and Keck Spectra of all Kepler RRLyr stars
Spectroscopic Studies

2010

An in-depth spectroscopic analysis of the Blazhko star RR Lyrae
I. Characterisation of the star: abundance analysis and fundamental parameters
K. Kolenberg1, L. Fossati2, D. Shulyak3, H. Pikal1, T. G. Barnes4, O. Kochukhov5 and V. Tsybval6

2013

An In-Depth Spectroscopic Analysis of RR Lyr Variations over the Pulsation Cycle
L. Fossati1 *, K. Kolenberg2,3, A. Elmasli4, D. Shulyak5, E. Guggenberger4, T.G. Barnes7, O. Kochukov8, V. Tsybval9
“quiet(er) phase” (maximum radius)
Abundance analysis (EW) – detailed element abundances
--- effective temperature, gravity, depth-dependent microturbulence
RR Lyr in short cadence
RR Lyr in short cadence

Initially a Kepler GO Program - THANK YOU!
Data from 1912

Data by Kepler, a century later
Flux

A NEW ERA

… and we have simultaneous short-cadence spectroscopy!
NONLINEAR ASTEROSEISMOLOGY OF RR LYRAE

L. Molnár¹, Z. Kolláth¹, R. Szabó¹, S. Bryson², K. Kolenberg³,4, F. Mullally²,5, and S. E. Thompson²,5
Period shorter at Blazhko maximum

Pulsation Period

Stellingwerf, Nemec, Moskalik (2013)
Blazhko Period

Stellingwerf, Nemec, Moskalik (2013)
Explanations for the Blazhko Effect

2006-2010, pre-Kepler
Explanations for the Blazhko Effect

- Radial Resonance
  - $l = 0$
- Shock Model
  - $l = 0$
- Resonance Model
- Magnetic Model
  - $l = 2$
- ‘Starspot’ Mechanism

Detlefsen & Secord 1993
Flux
pre-1913
2011

... and we have simultaneous short-cadence spectroscopy!
Figure 5: Short-cadence Kepler data and the timing of the simultaneous short-cadence spectra (blue). Phase of maximum radius is indicated in orange.
Figure 6: One order of a representative 1-minute spectrum of RR Lyr containing the H_gamma line.
Radial Velocity (km/s)

3-5 km/s shift
Bump Strength

Blazhko Phase

Work of Ba-student Pieter Schillemans
… still lots of data to explore … find new RR Lyrae stars …
Thanks so much, Kepler Team!
… still lots of data to explore … find new RR Lyrae stars …