

STELLAR PULSATIONS
IN THE
OGLE
SURVEY

Igor Soszyński

University of Warsaw Astronomical Observatory

The OGLE team

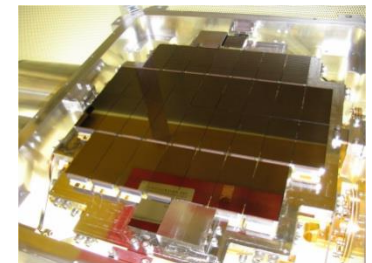
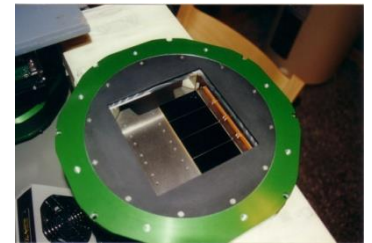
- **Andrzej Udalski**
- Michał Szymański
- Grzegorz Pietrzyński
- Igor Soszyński
- Łukasz Wyrzykowski
- Krzysztof Ulaczyk
- Radosław Poleski
- Paweł Pietrukowicz
- Szymon Kozłowski
- Jan Skowron



- Dorota Skowron
- Przemysław Mróz
- Michał Pawlak

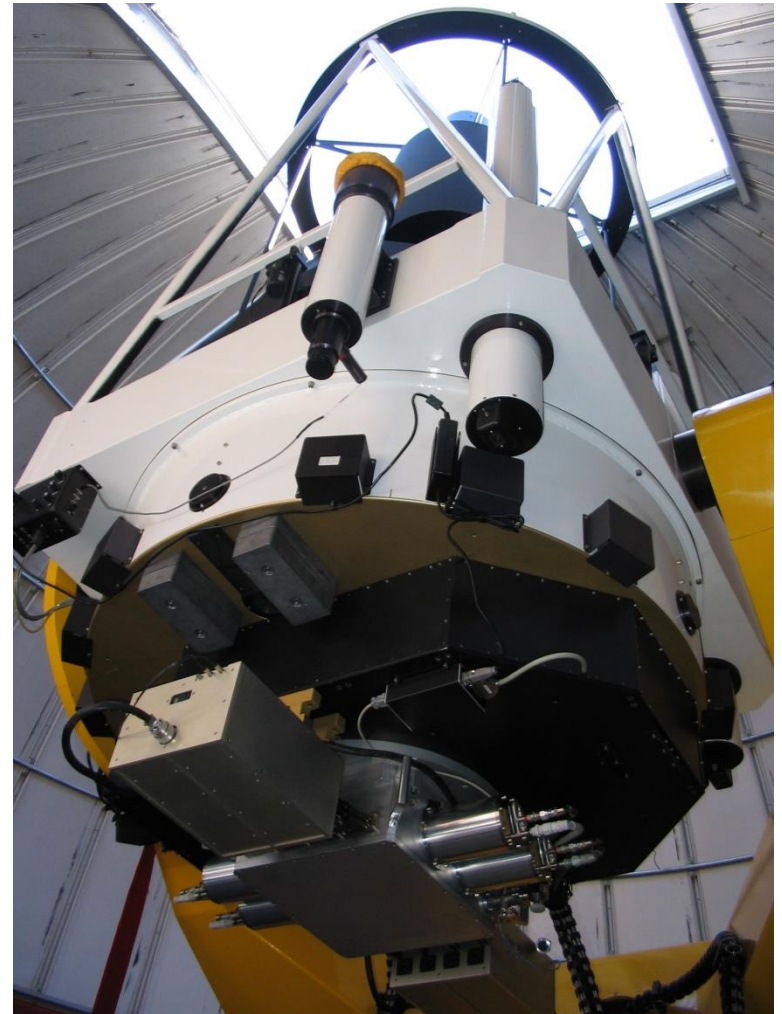
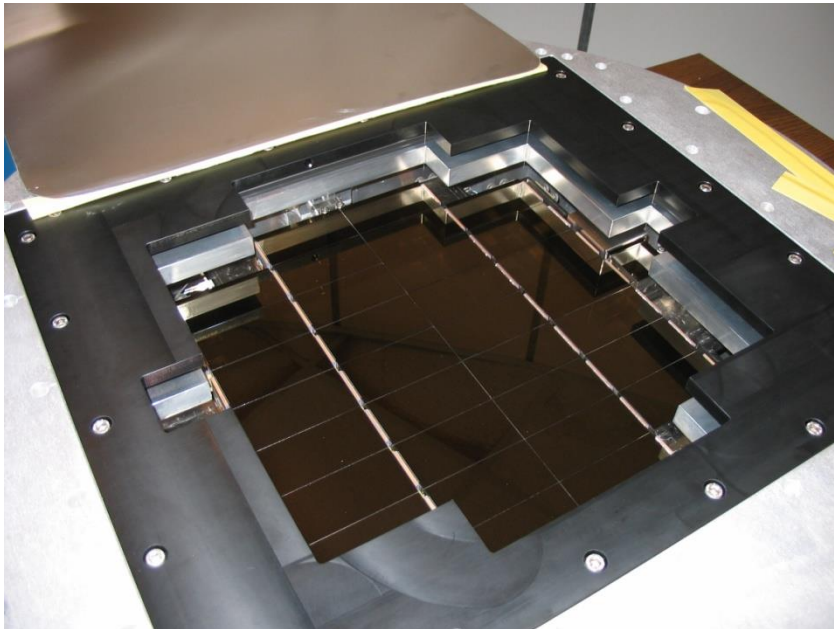
The OGLE project – history

- **OGLE-I** 1992 – 1995
 $2 \cdot 10^6$ stars observed
- **OGLE-II** 1997 – 2000
 $4 \cdot 10^7$ stars observed
- **OGLE-III** 2001 – 2009
 $4 \cdot 10^8$ stars observed
- **OGLE-IV** 2010 – ...
 $\sim 10^9$ stars observed



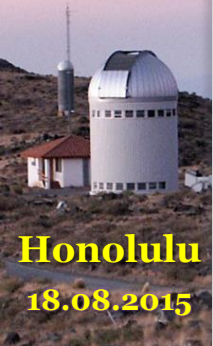
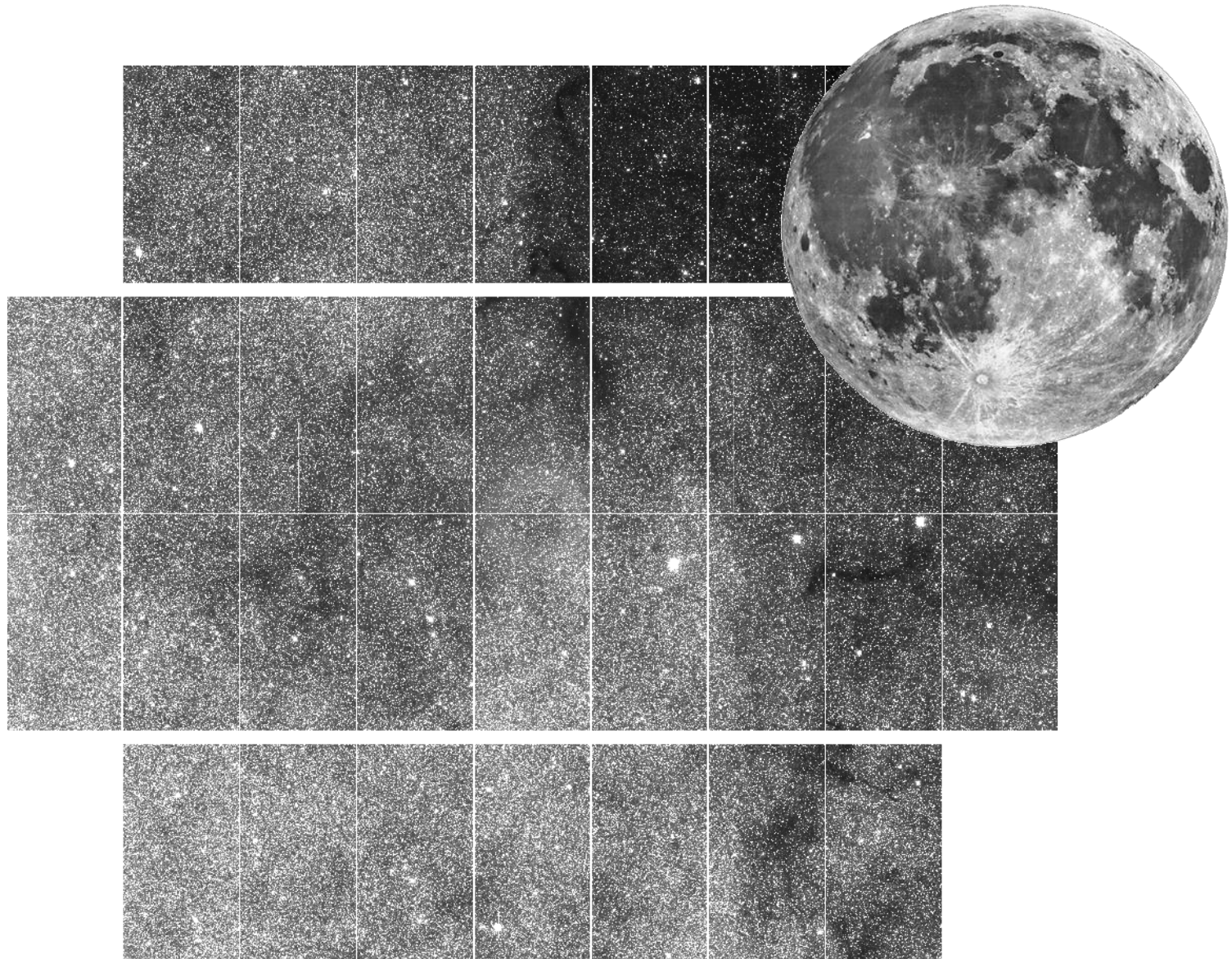
OGLE-IV mosaic CCD camera

- **32 chips 256 Mpix. CCD mosaic camera**
(+ **2 chips for guiding**)
- **1.4 square degrees field**





OGLE-IV mosaic CCD camera



OGLE fields

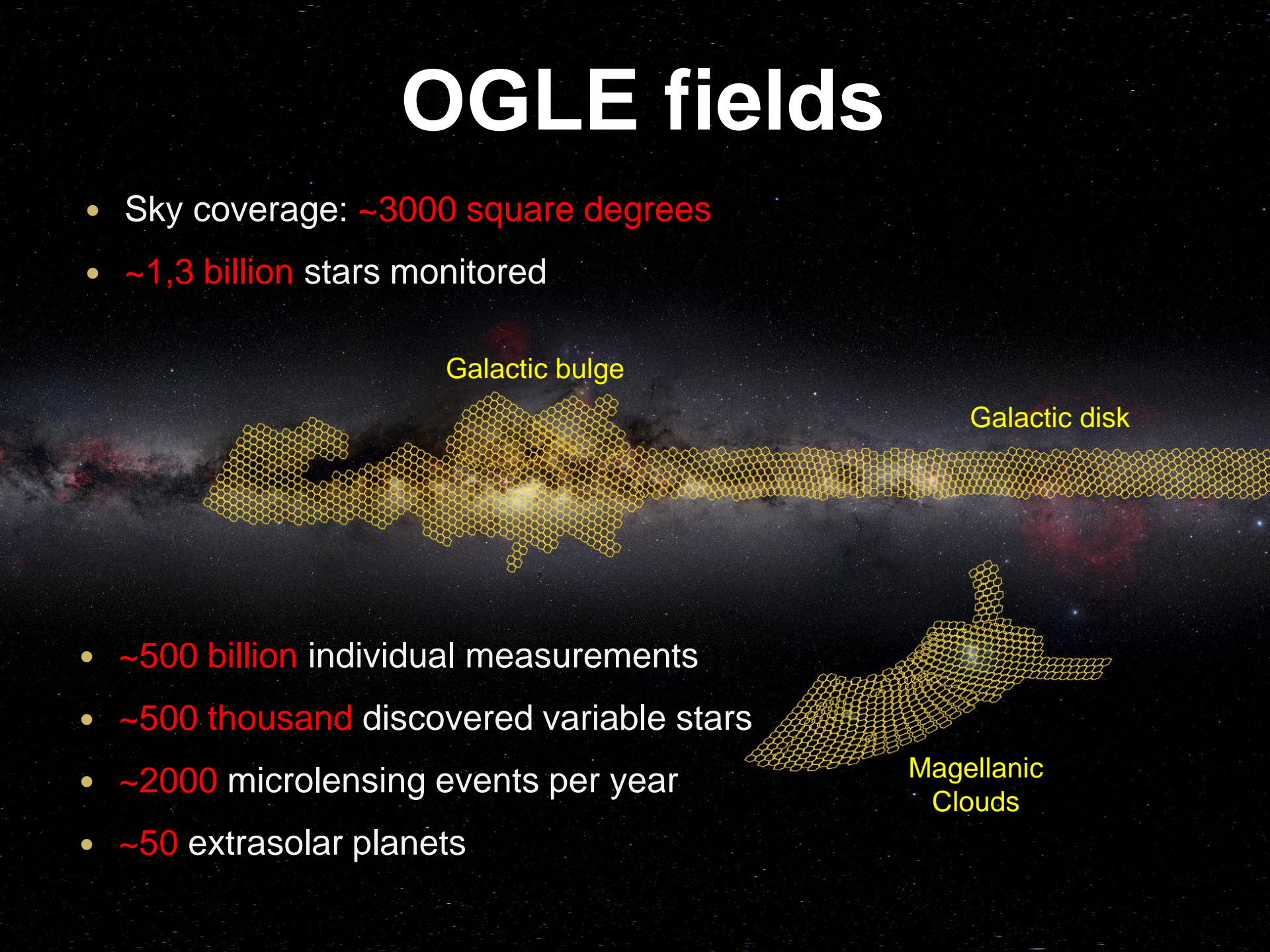
- Sky coverage: **~3000 square degrees**
- **~1,3 billion** stars monitored

Galactic bulge

Galactic disk

- **~500 billion** individual measurements
- **~500 thousand** discovered variable stars
- **~2000** microlensing events per year
- **~50** extrasolar planets

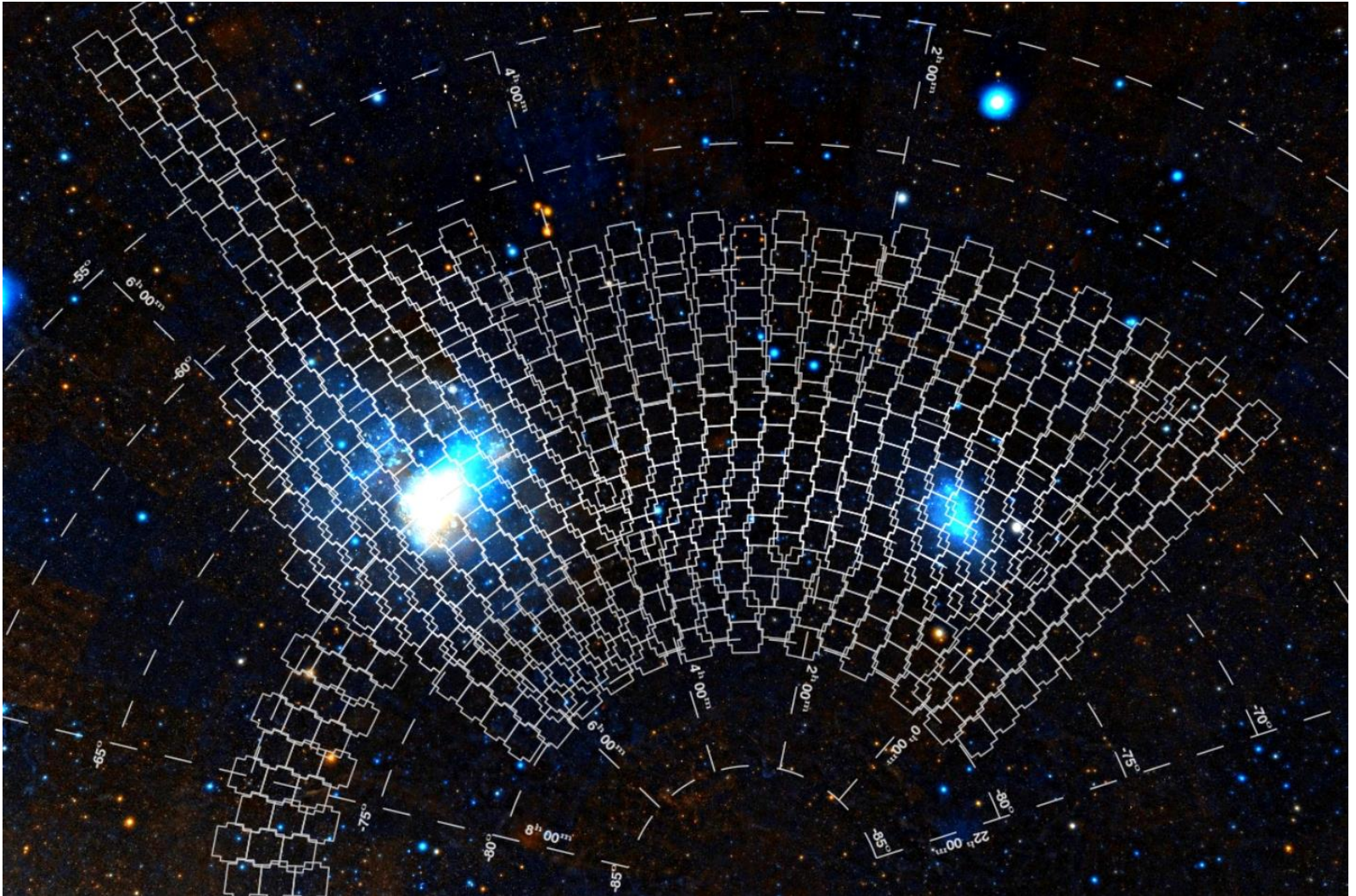
Magellanic
Clouds

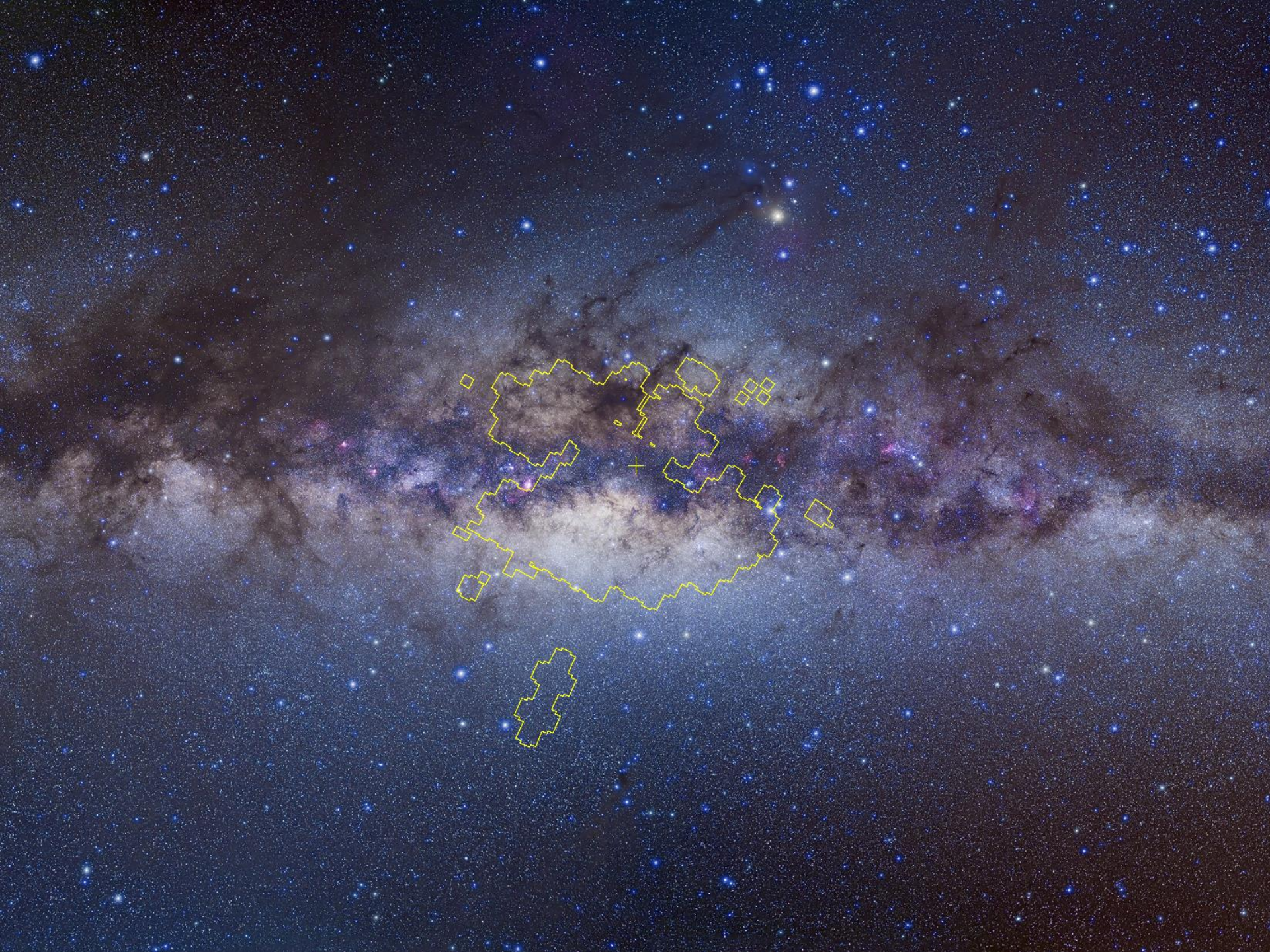


OGLE fields in the Magellanic Clouds

650 square degrees

~80 million stars





OGLE Collection of Variable Stars

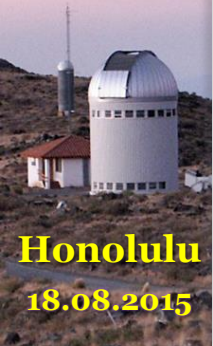
Type of variable stars	Environments	Number of stars
Classical Cepheids	LMC, SMC, GB	8 037
Type II Cepheids	LMC, SMC, GB	581
Anomalous Cepheids	LMC, SMC	250
RR Lyrae stars	LMC, SMC, GB	65 638
δ Scuti stars	LMC, GD	2 844
Long-Period Variables (Miras, SRVs, OSARGs)	LMC, SMC, GB	344 214
Eclipsing binaries	LMC, SMC, GD	43 845
R Coronae Borealis stars	LMC	23
TOTAL		465 432

OGLE Collection of Variable Stars

Principles:

- **Classification** of all objects
- **High completeness**
- **Identification** with other catalogs
- **Series of papers** (methods, statistical analysis, interesting cases)
- Publication of the **full OGLE light curves**
- **Open structure**

CLASSICAL CEPHEIDS

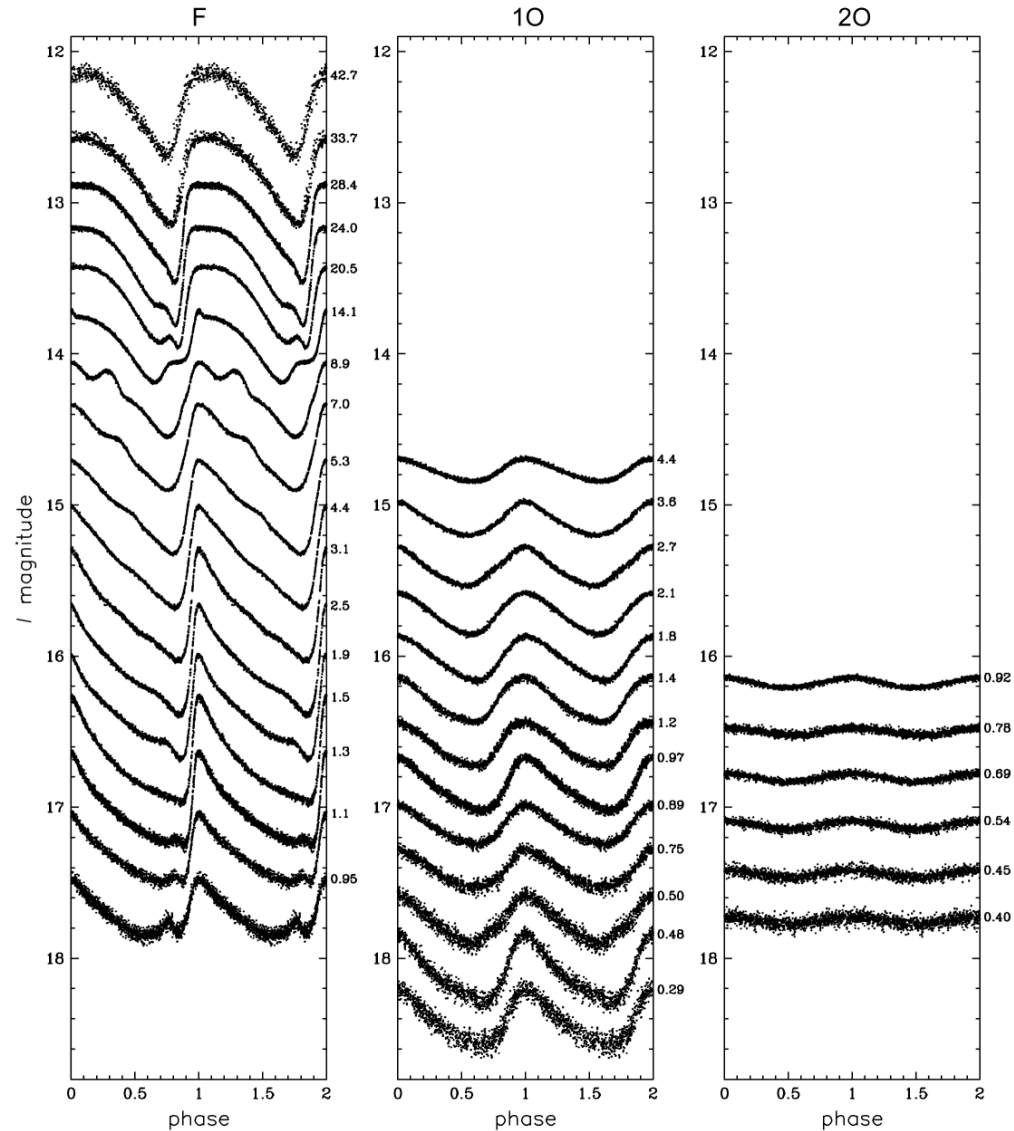


Classical Cepheids

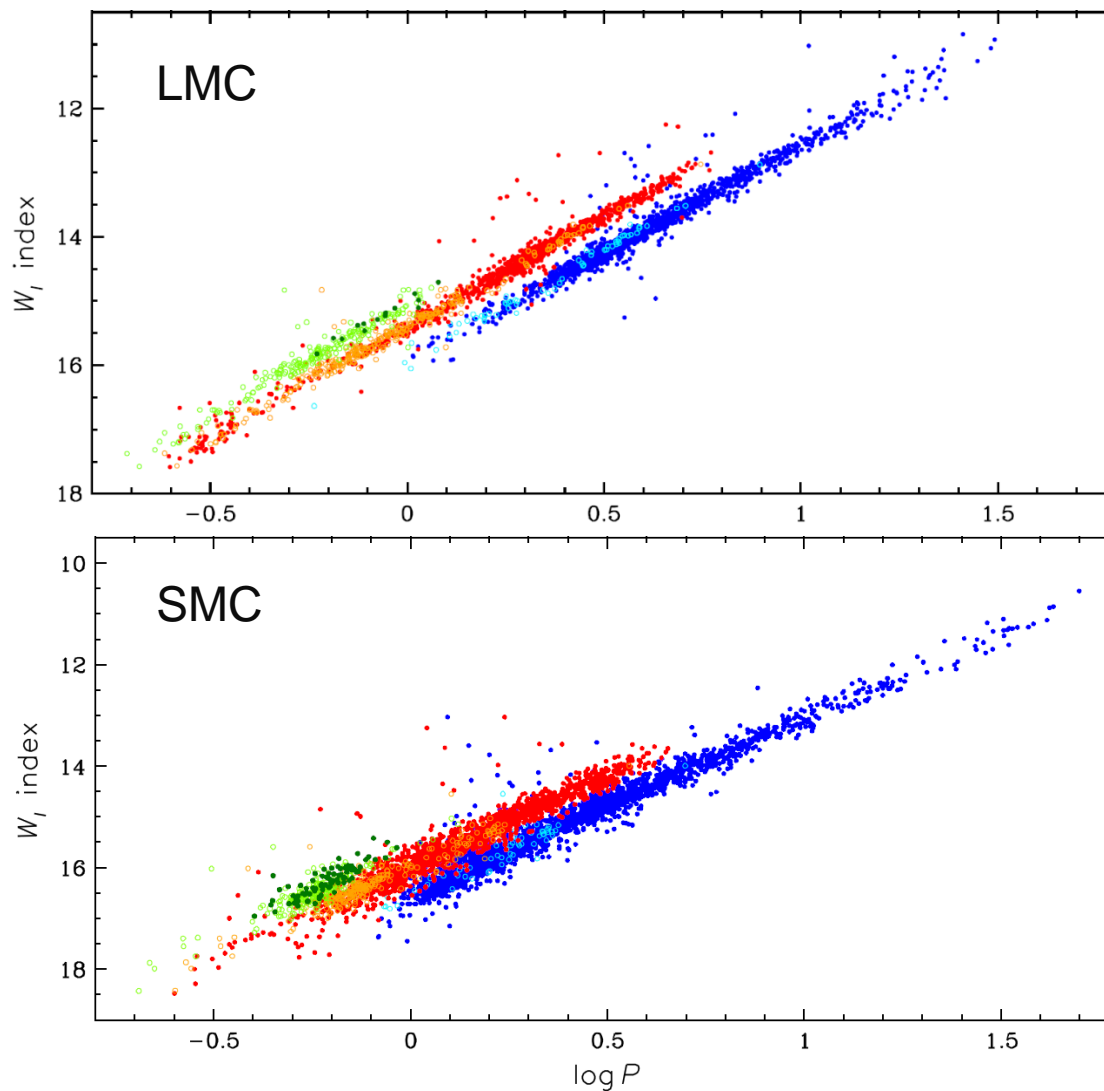
LMC: 3375 objects

SMC: 4630 objects

GB: 32 objects

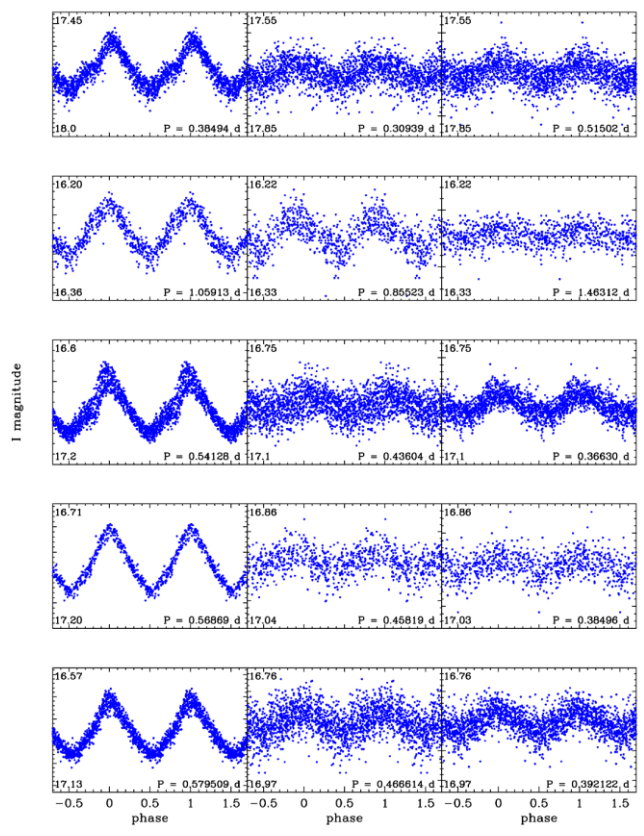
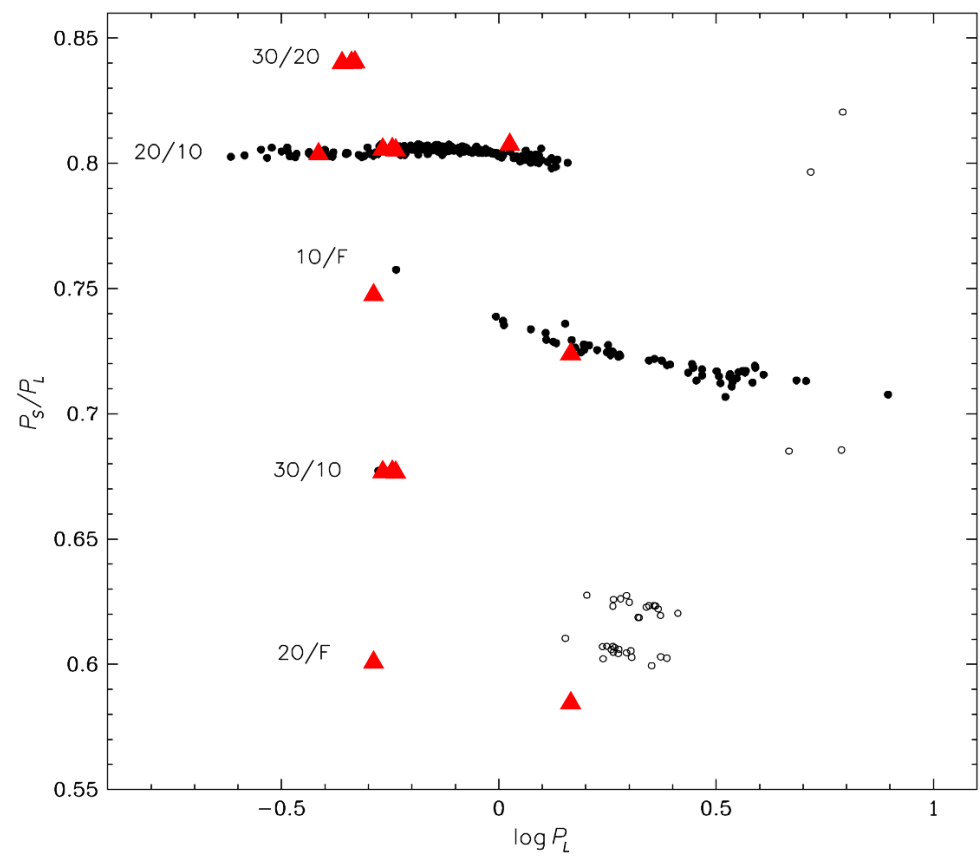


Period-luminosity relations of classical Cepheids



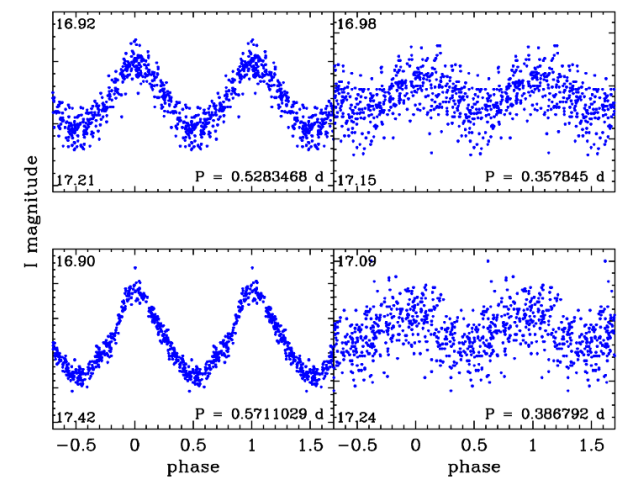
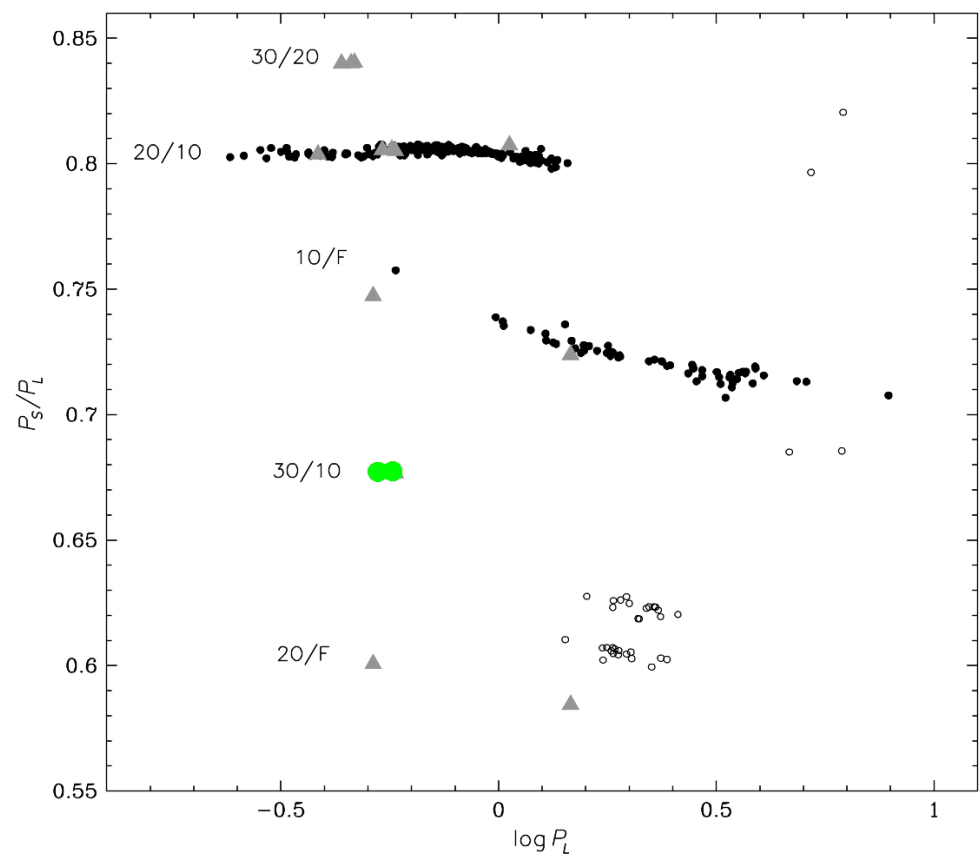
Triple-mode Cepheids

5 in the LMC, 3 in the SMC, 2 in the Bulge
 4 F/10/20 6 10/20/30



Double-mode 10/30 Cepheids

2 stars in the LMC

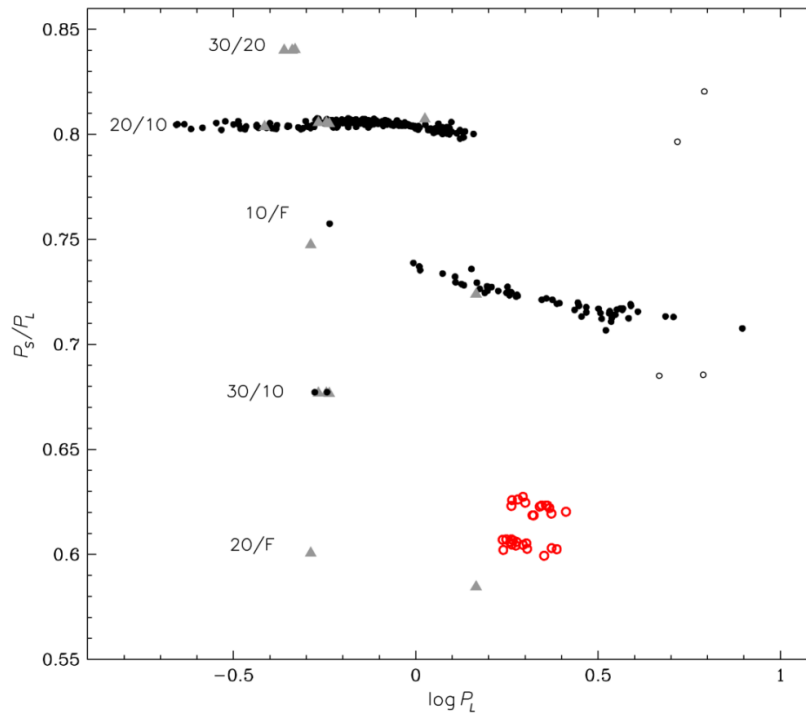


$$P_S/P_L = 0.677$$

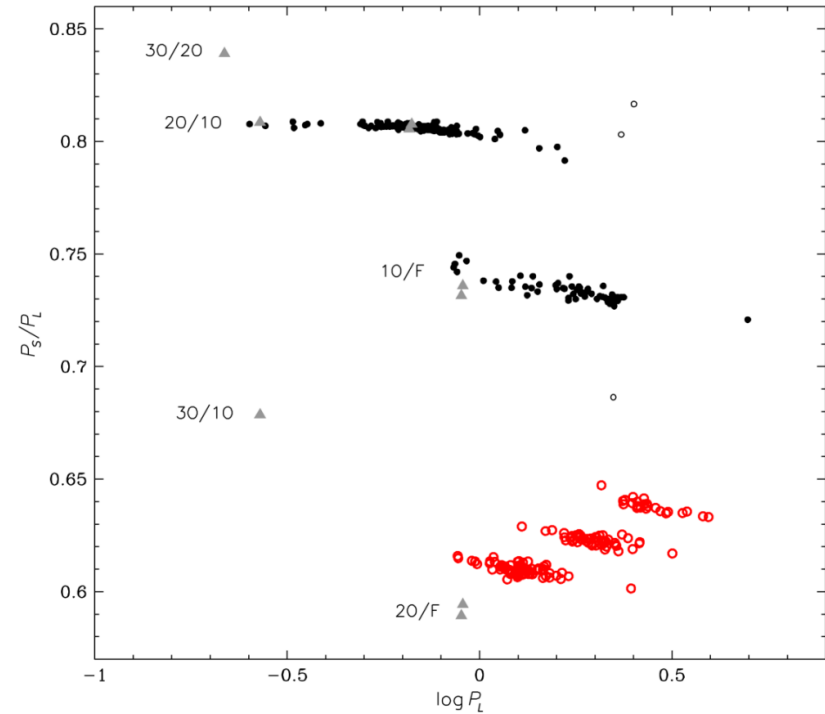
Classical Cepheids in the MCs

Non-radial modes in the first-overtone Cepheids

$$P_X/P_{10} = 0.60 - 0.64$$



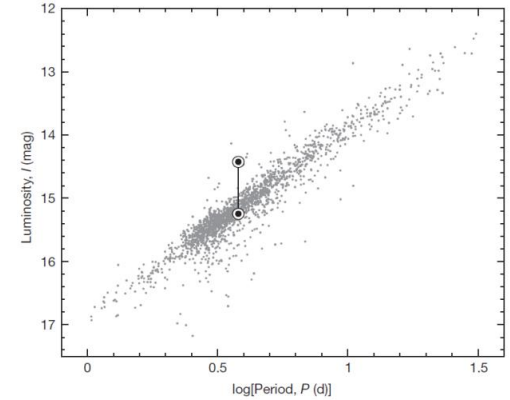
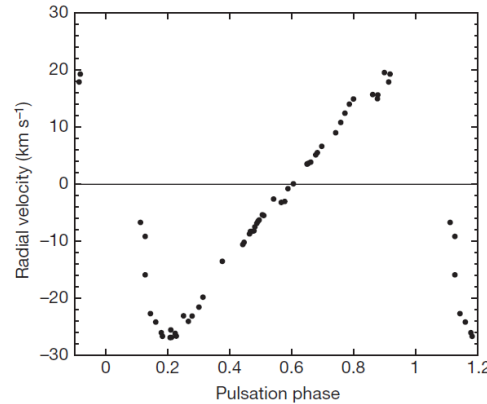
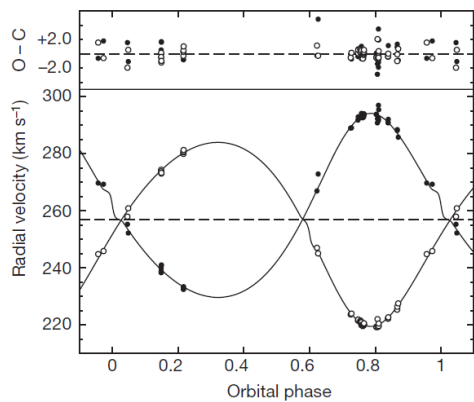
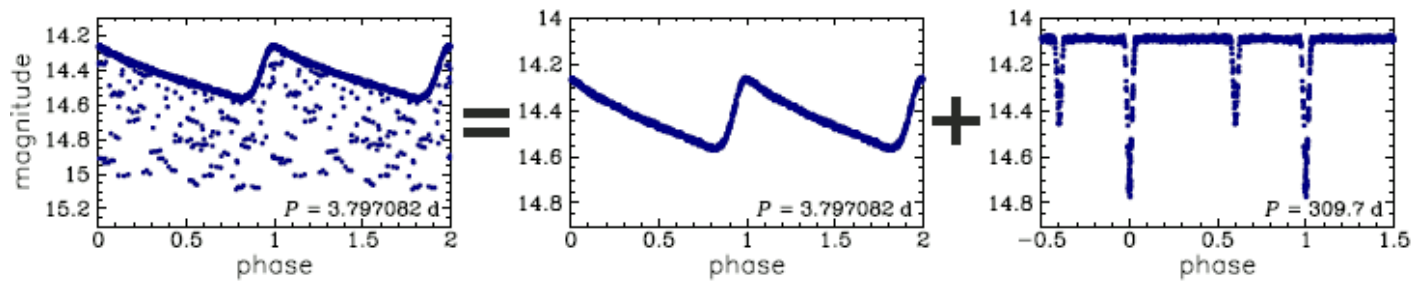
LMC: 30 objects



SMC: 139 objects

Classical Cepheids in eclipsing binary systems

OGLE-LMC-CEP-0227



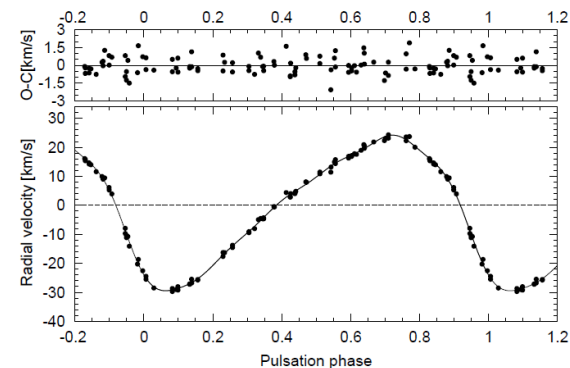
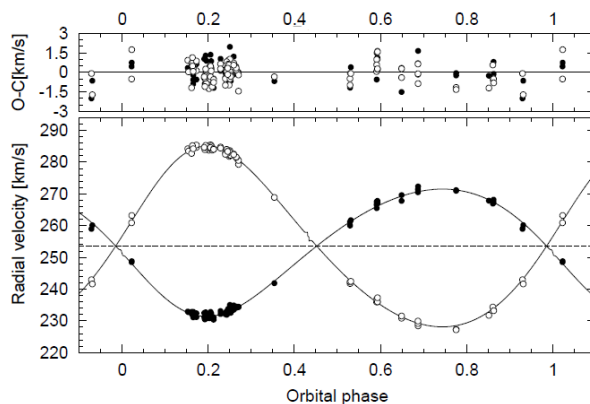
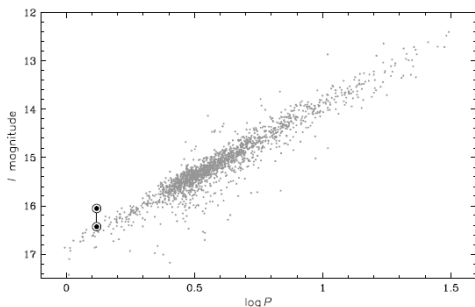
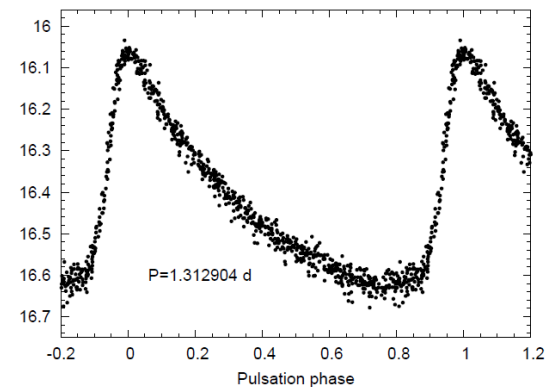
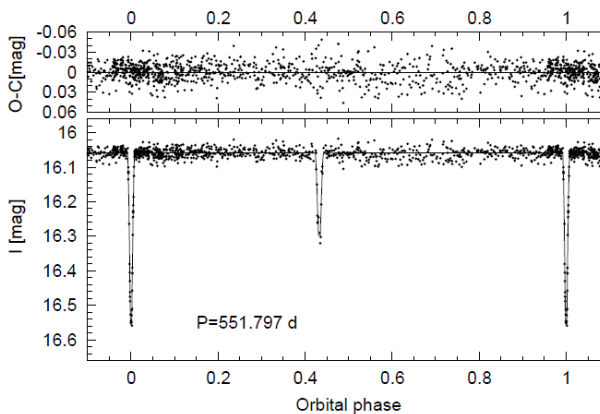
Cepheid mass: $4.14 \pm 0.05 M_{\odot}$

Classical Cepheids in eclipsing binary systems

OGLE-LMC-CEP-1812

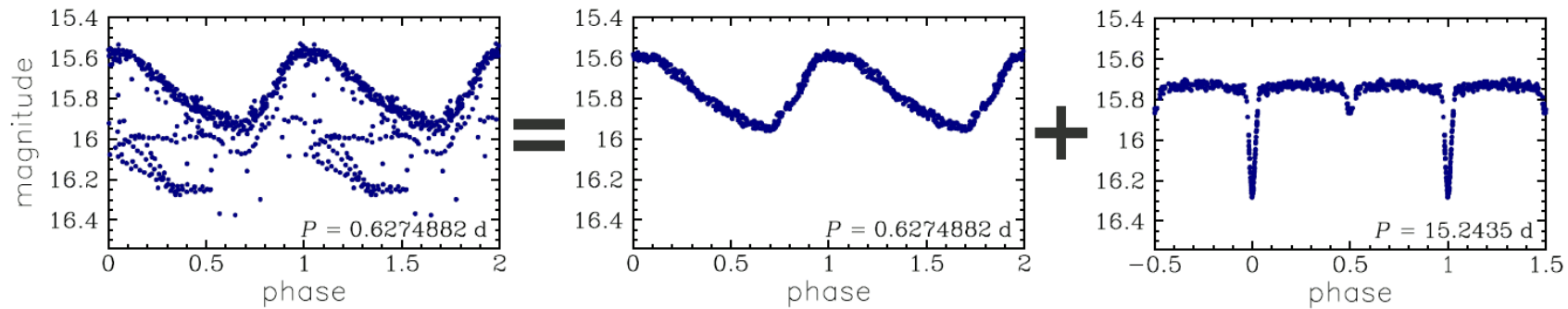
Pietrzyński et al. (2011)

Cepheid mass:
 $3.74 \pm 0.06 M_{\odot}$



RR Lyrae stars

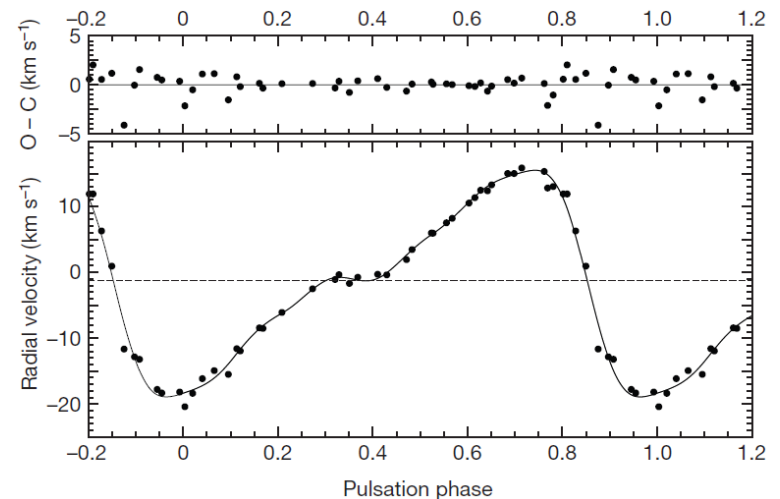
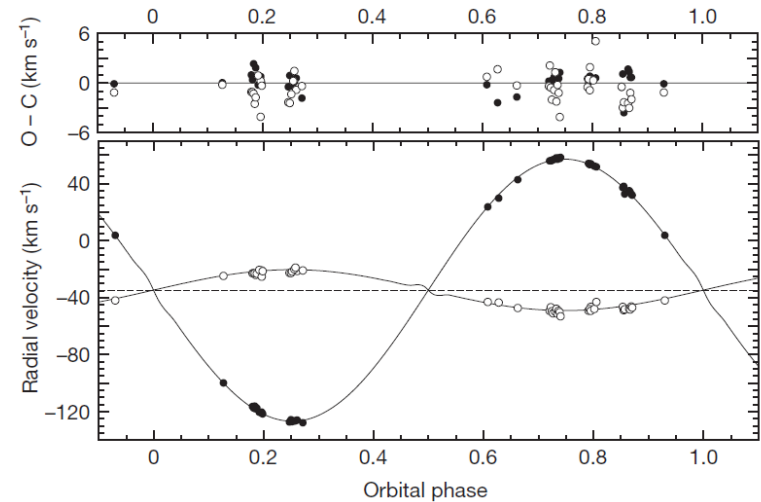
An RR Lyrae star in the binary system?



RR Lyrae stars

No! Binary evolution pulsator

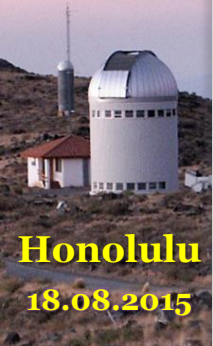
	Primary component (pulsator)	Secondary component
M/M_{\odot}	0.261 ± 0.015	1.67 ± 0.06
R/R_{\odot}	4.24 ± 0.24	4.27 ± 0.31
T_{eff}	$7320 \pm 160 \text{ K}$	$5000 \pm 150 \text{ K}$



Pietrzyński et al. (2012), Nature

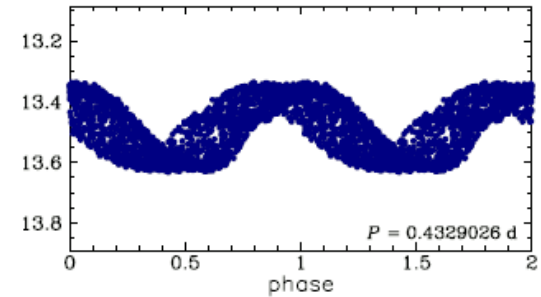
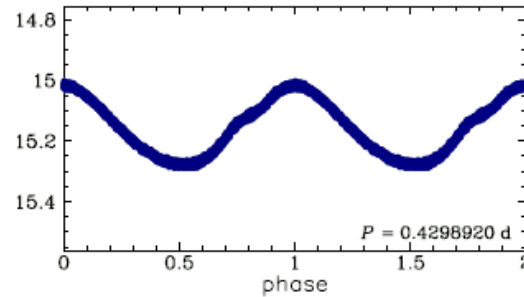
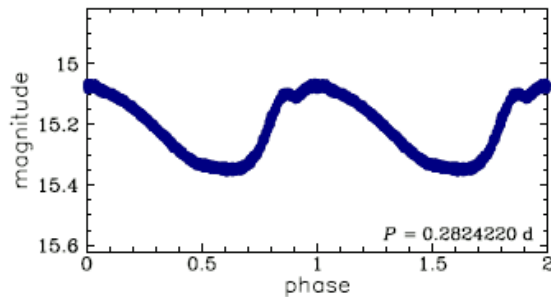
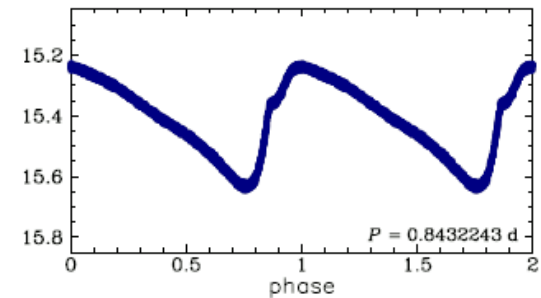
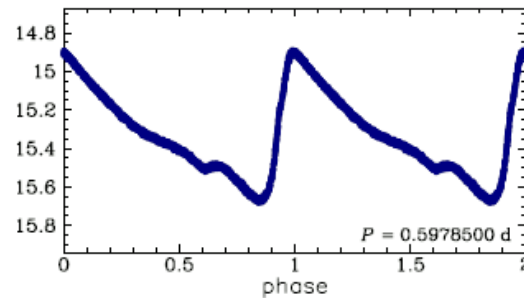
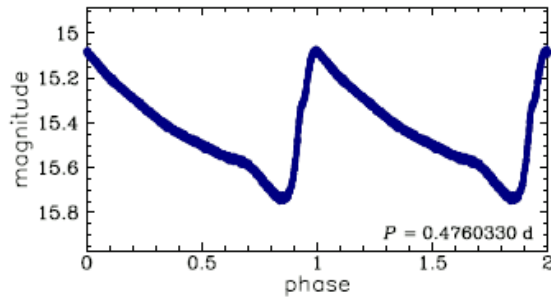


RR LYRAE STARS



RR Lyrae stars

<http://ogle.astrouw.edu.pl/atlas/>



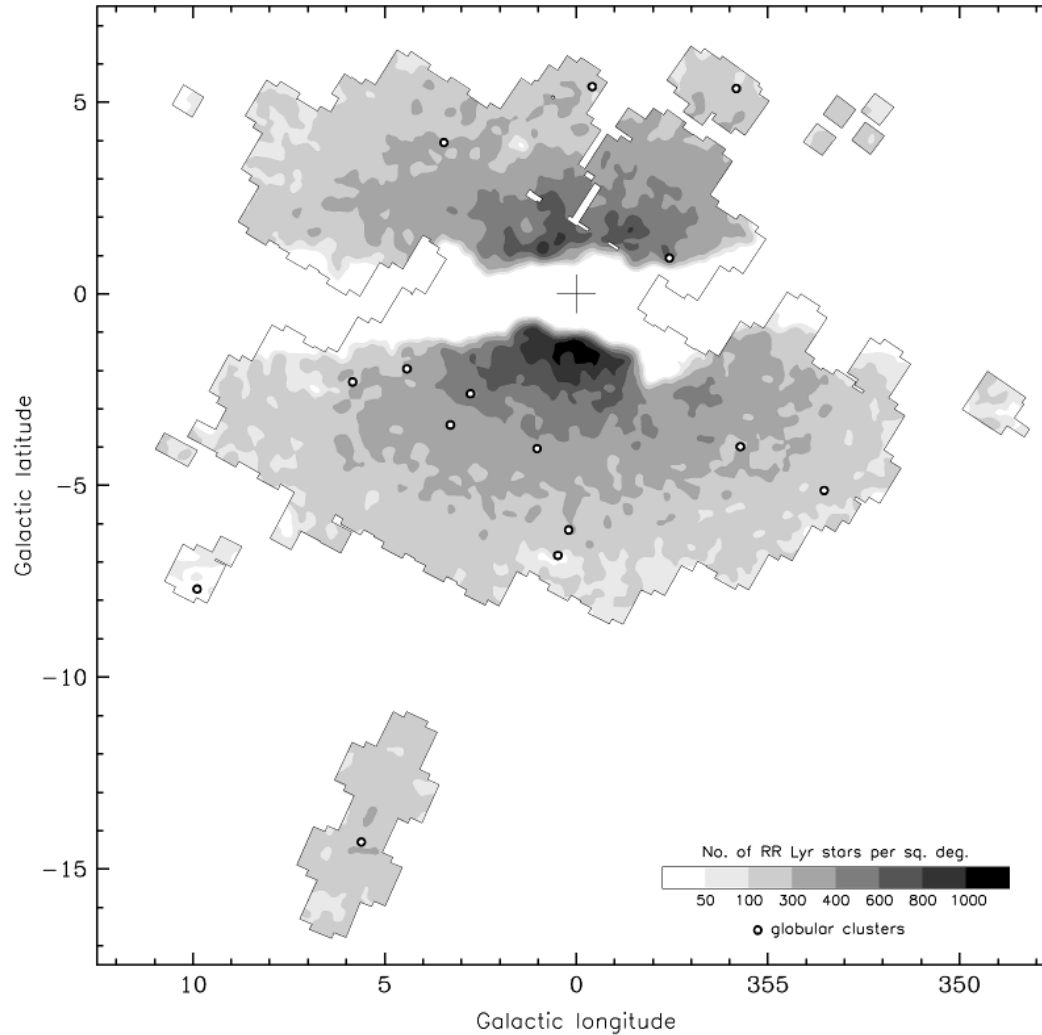
LMC: 24 906 objects

SMC: 2 475 objects

GB: 38 257 objects

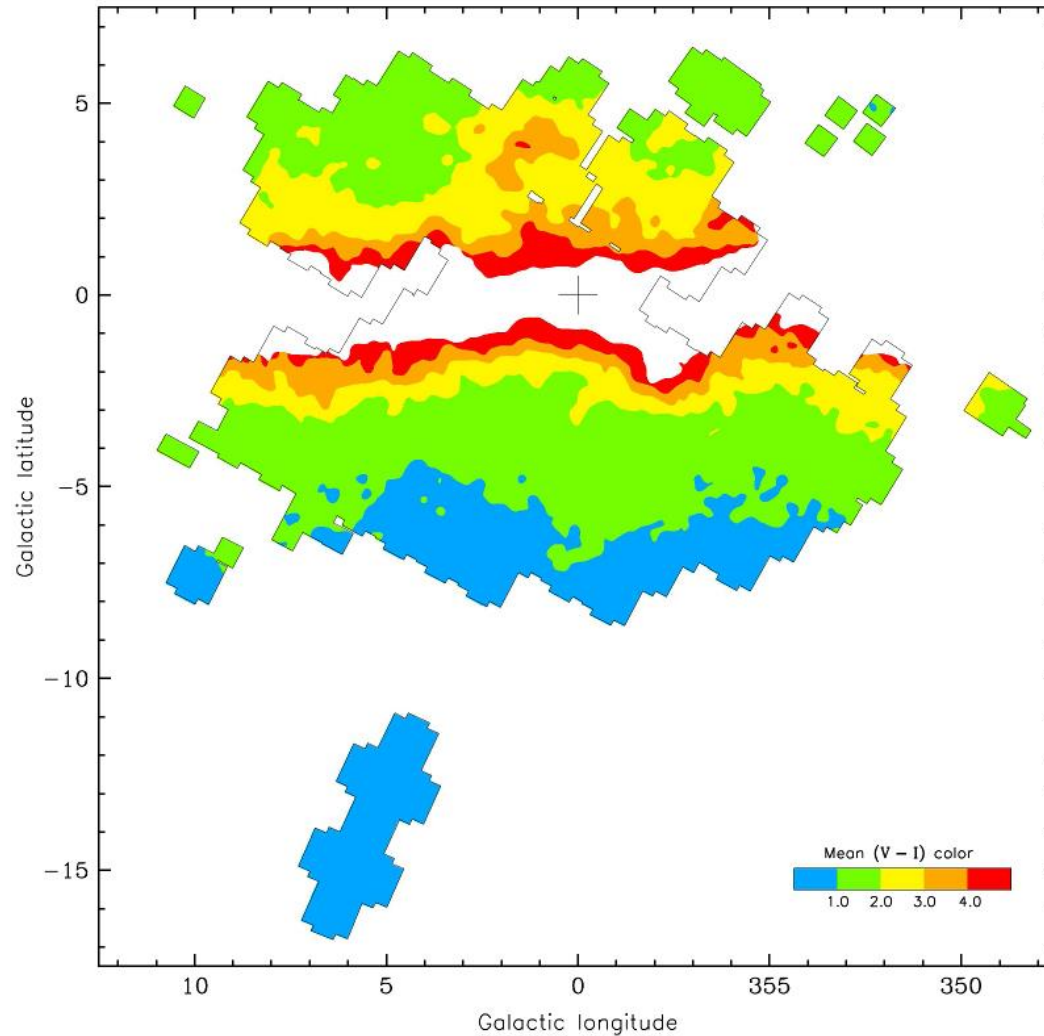
RR Lyrae stars in the Galactic bulge

38 257 RR Lyrae stars
Spatial distribution



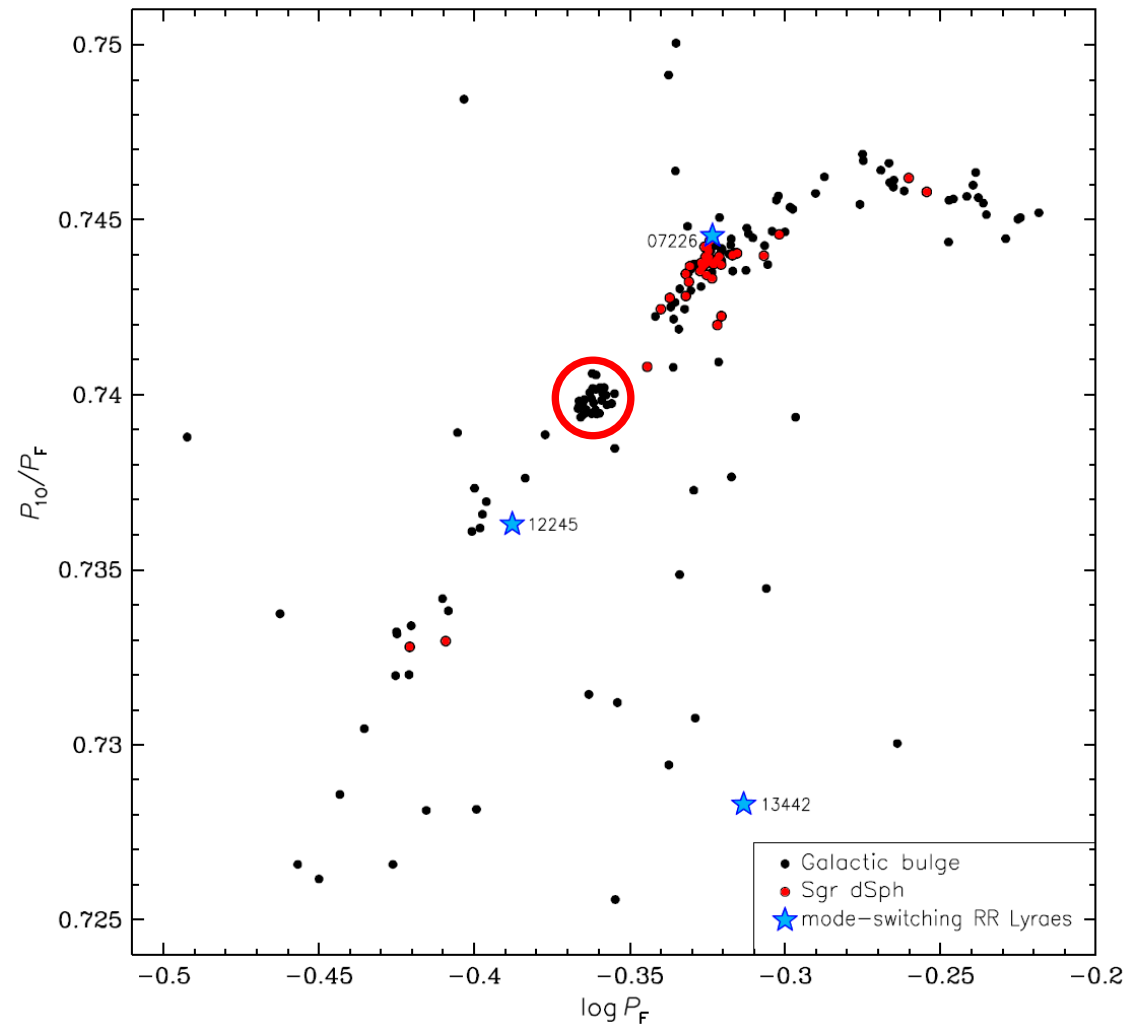
RR Lyrae stars in the Galactic bulge

Mean colors \rightarrow Extinction map



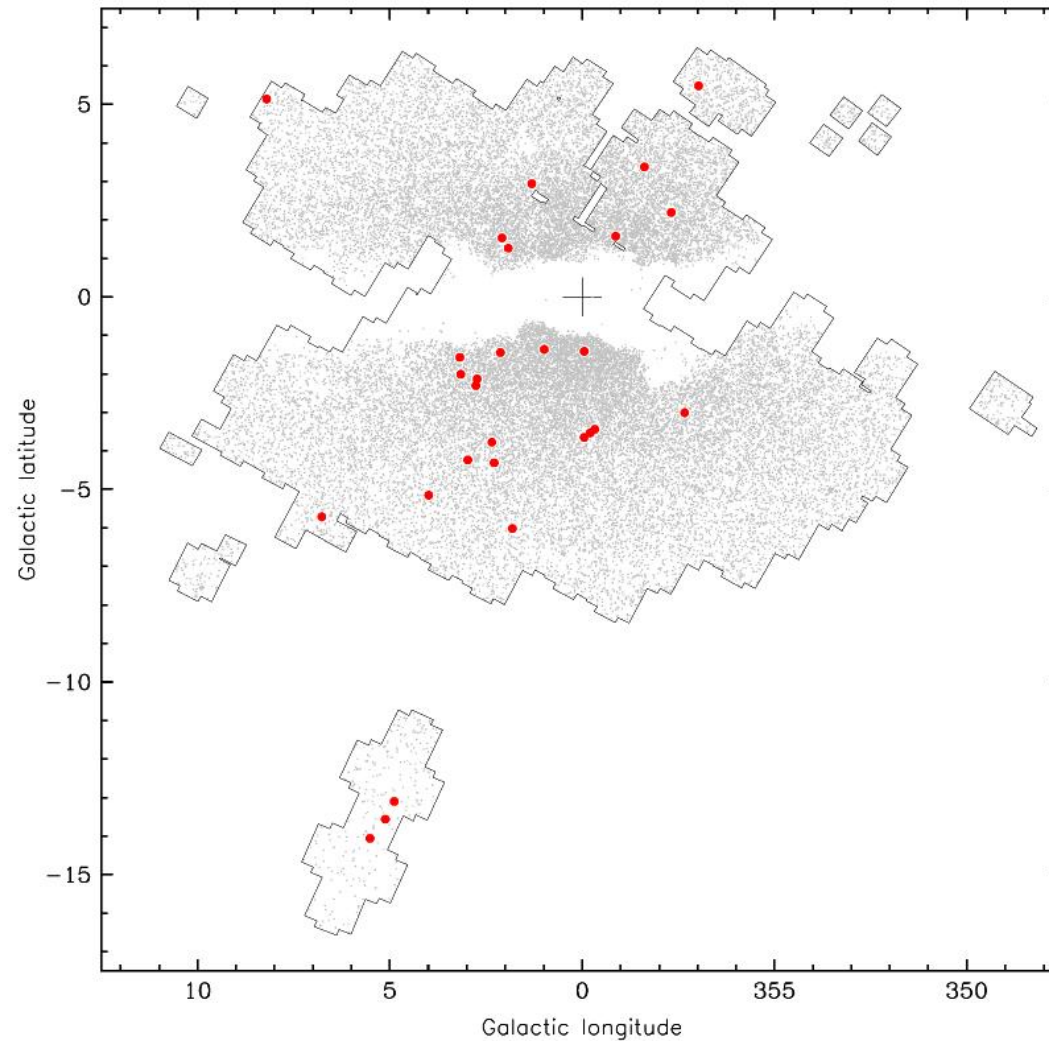
RR Lyrae stars in the Galactic Bulge

Petersen diagram for double-mode RR Lyrae stars (RRd)



RR Lyrae stars in the Galactic Bulge

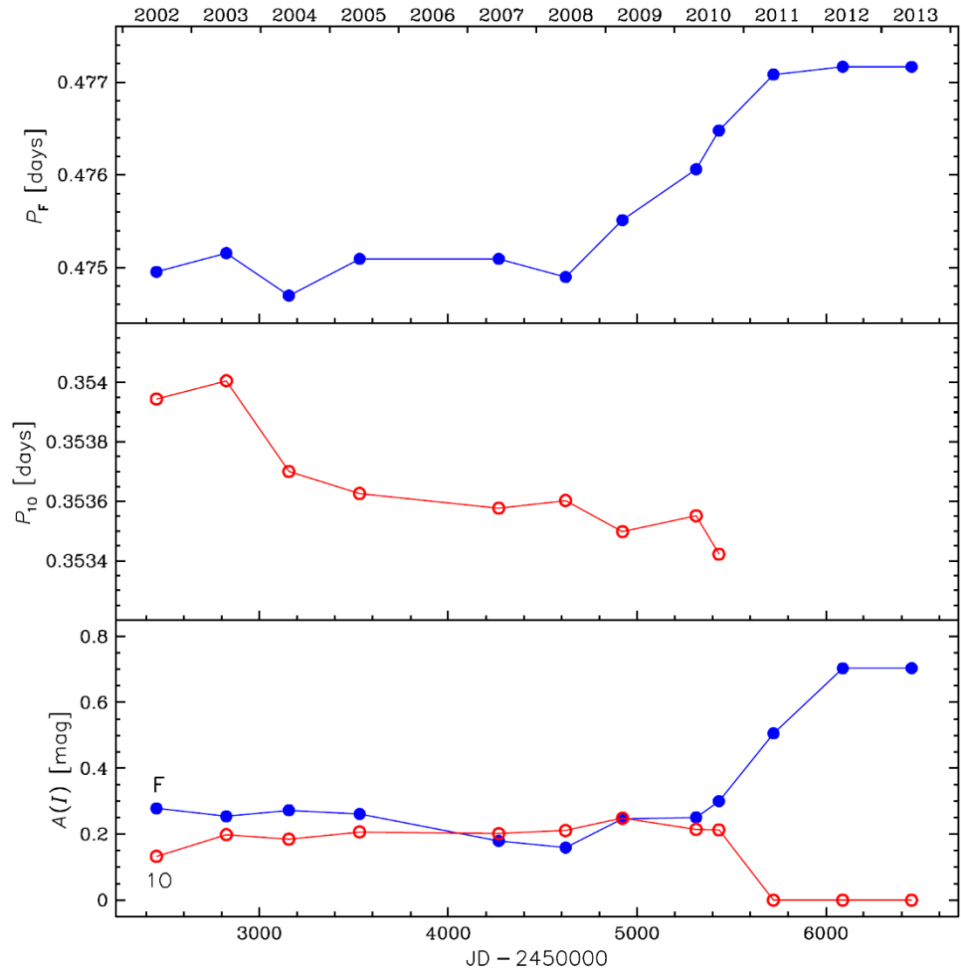
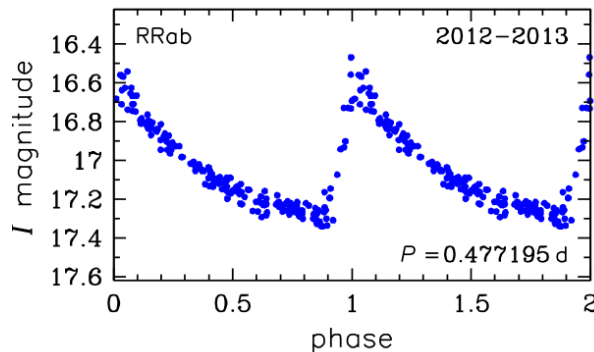
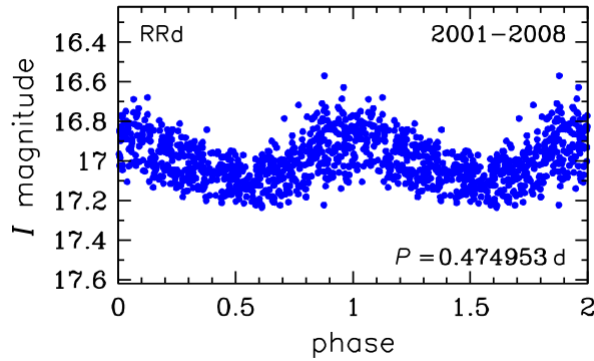
Positions of 28 RRd stars with $P_{10}/P_F \approx 0.740$



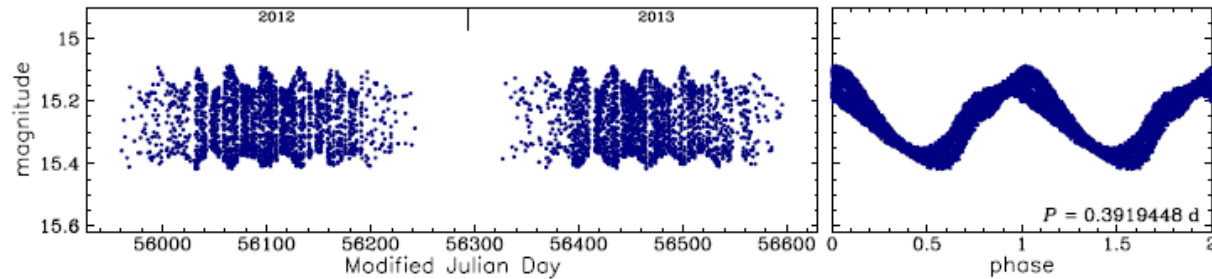
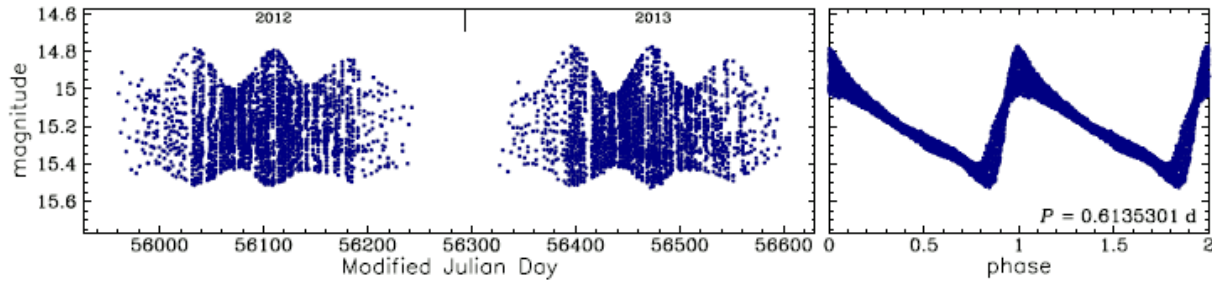
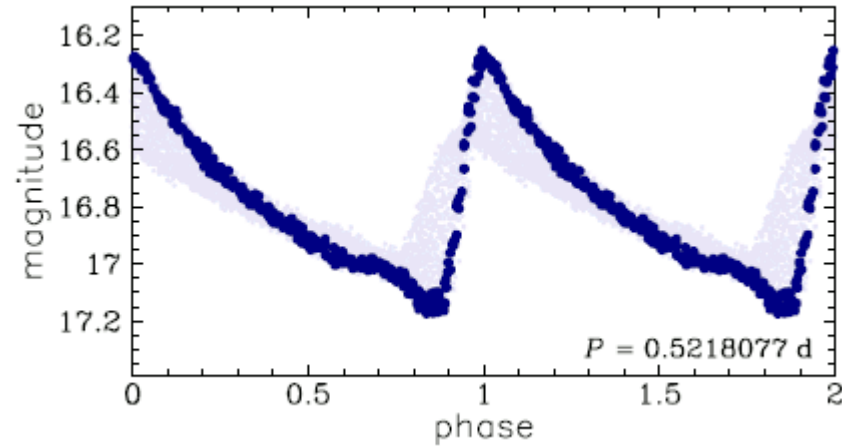
RR Lyrae stars in the Galactic Bulge

OGLE-BLG-RRLYR-07226

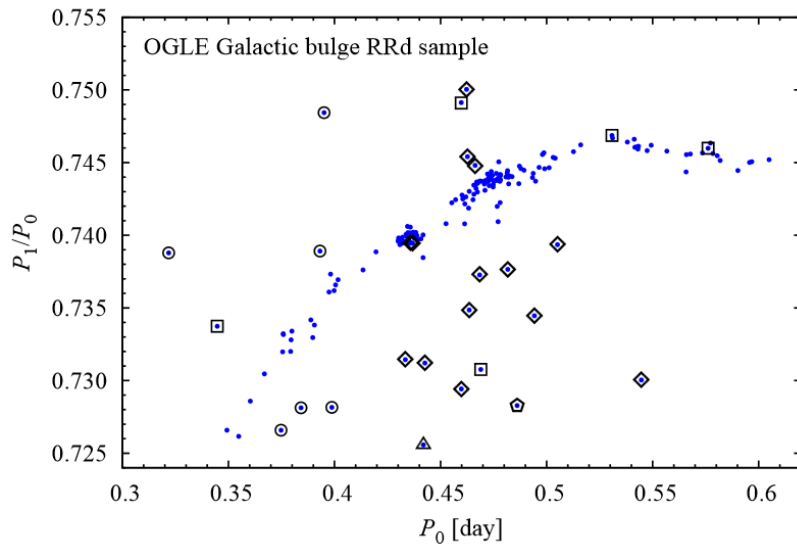
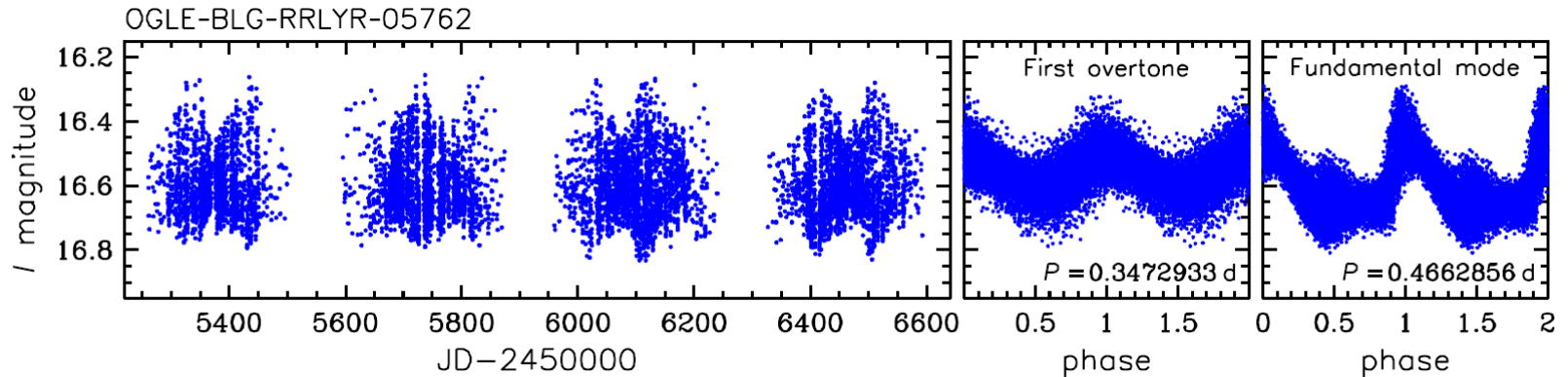
Switch of the pulsation mode from RRd to R Rab



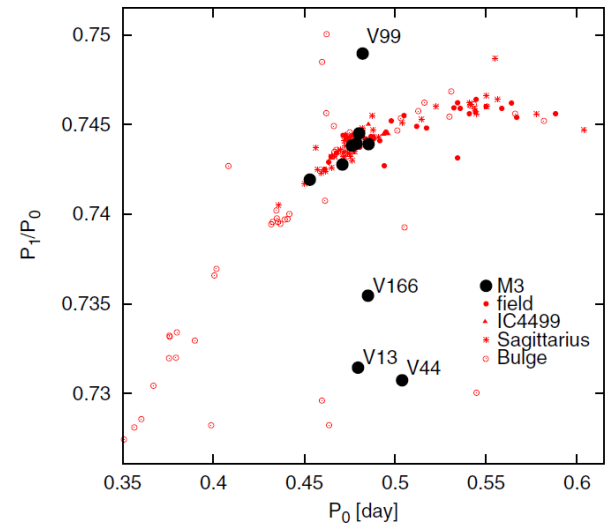
Blazhko effect in RR Lyrae stars



Blazhko effect in RRd stars



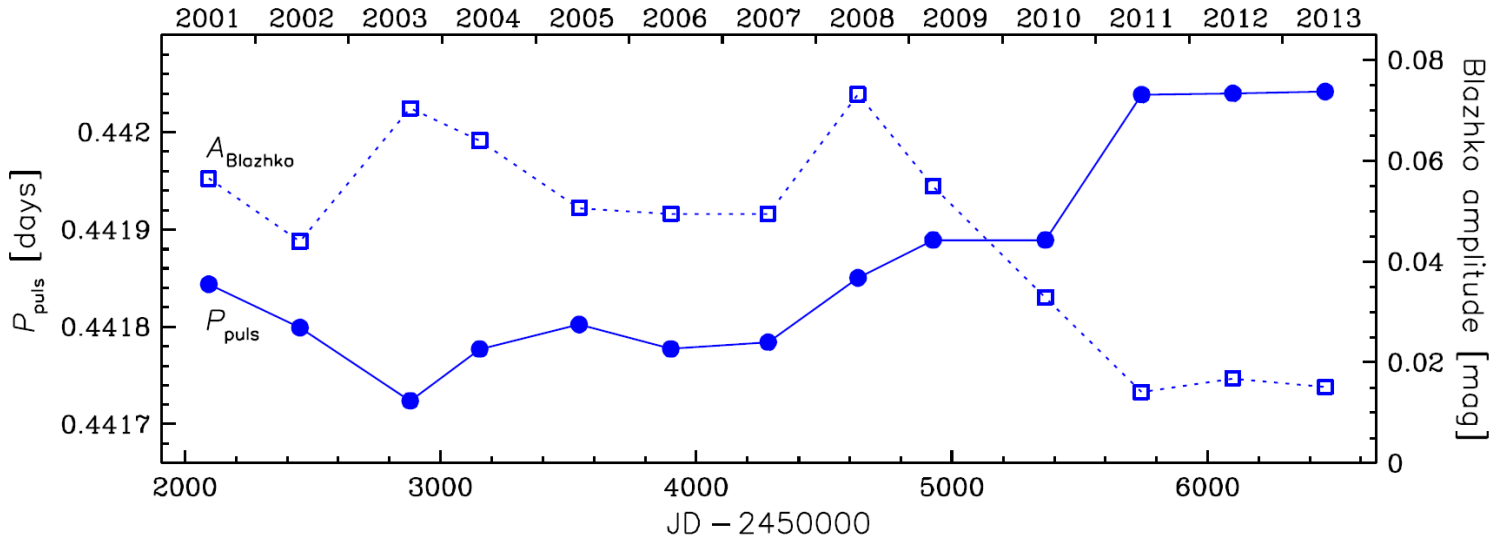
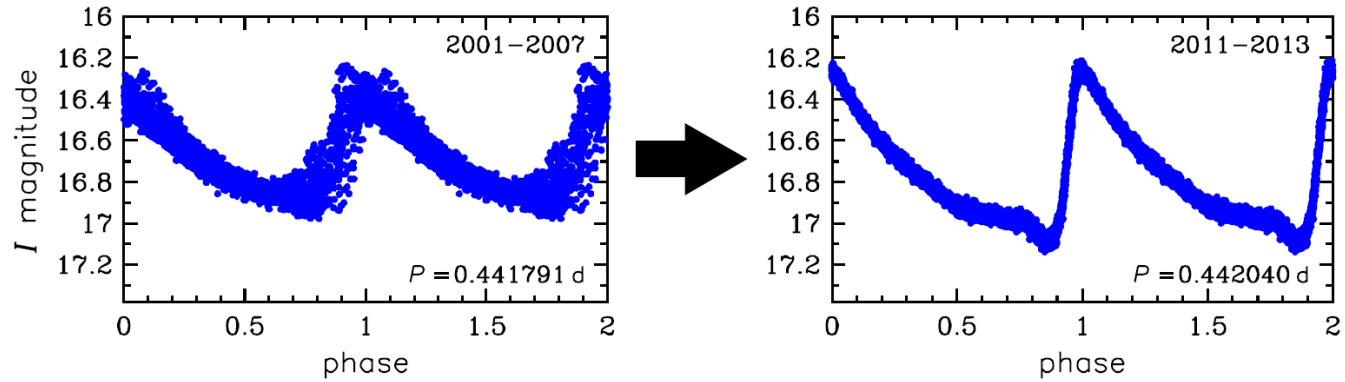
Smolec et al. (2014)



Jurcsik et al. (2014)

Blazhko effect in RR Lyrae stars

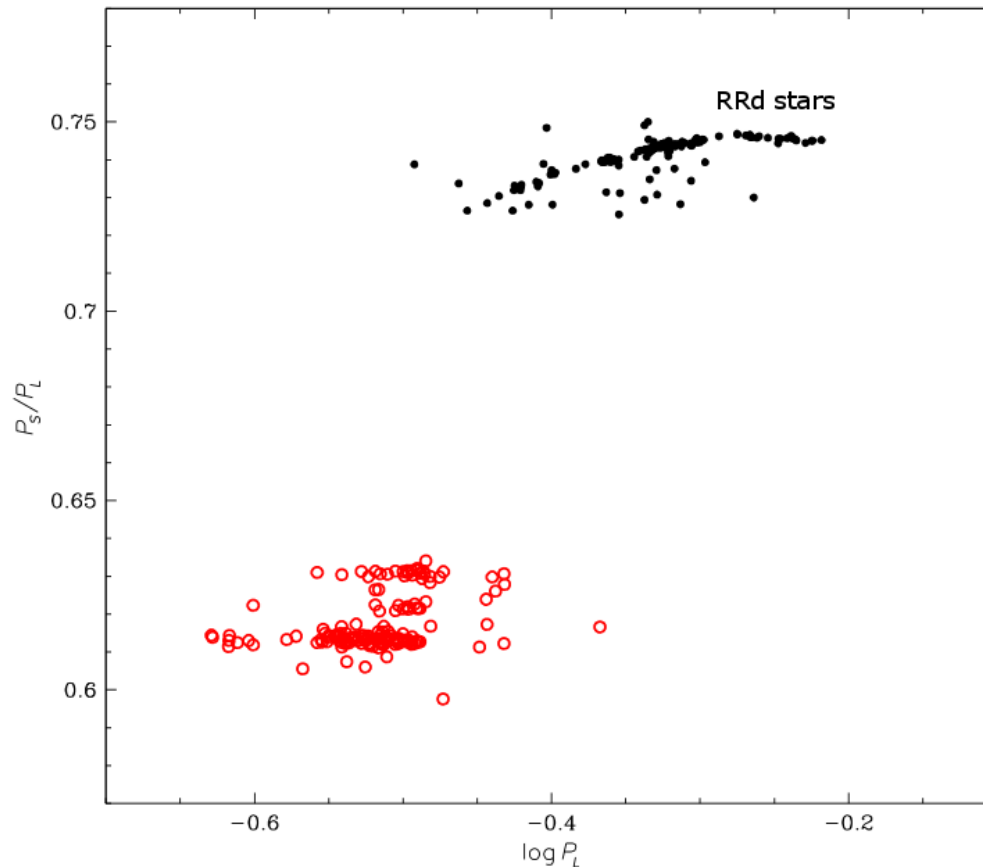
OGLE-BLG-RRLYR-07605



Non-radial modes in the first-overtone RR Lyrae stars

~300 stars

$$P_X/P_{10} = 0.60 - 0.64$$

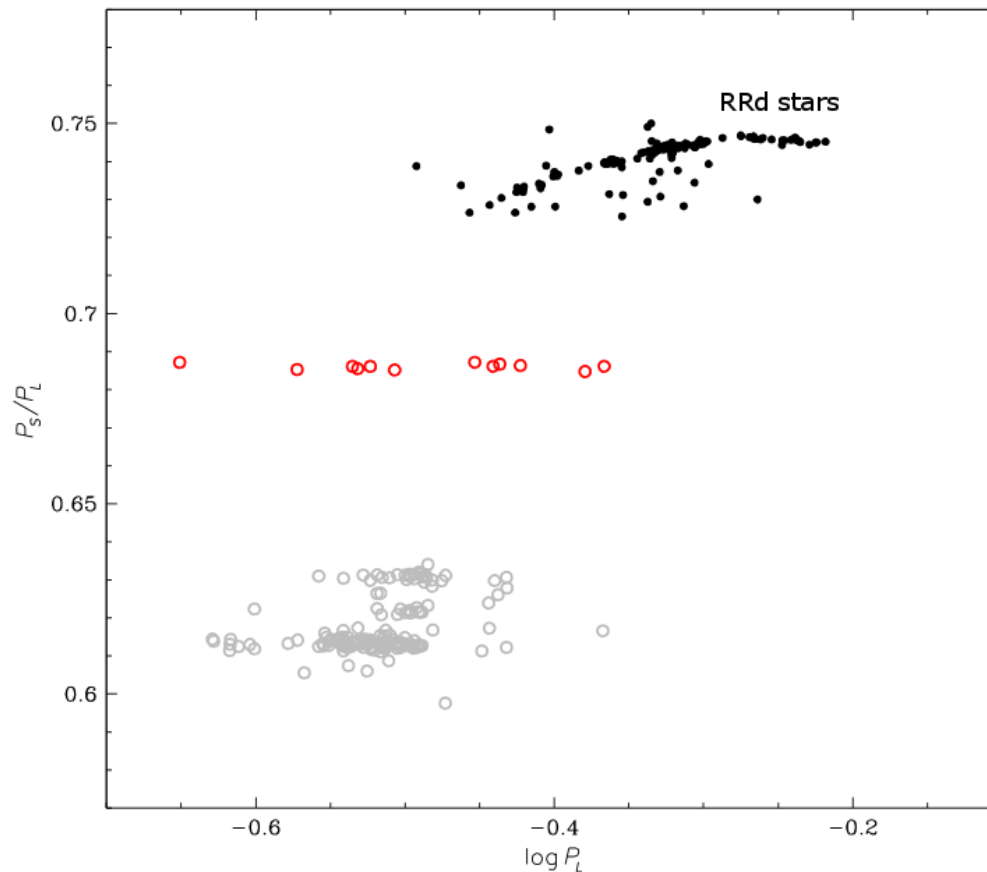


Netzel et al. (2015)

Non-radial modes in the first-overtone RR Lyrae stars

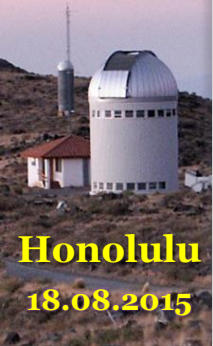
12 stars

$$P_{10}/P_X = 0.686$$



Netzel et al. (2015)

TYPE II CEPHEIDS

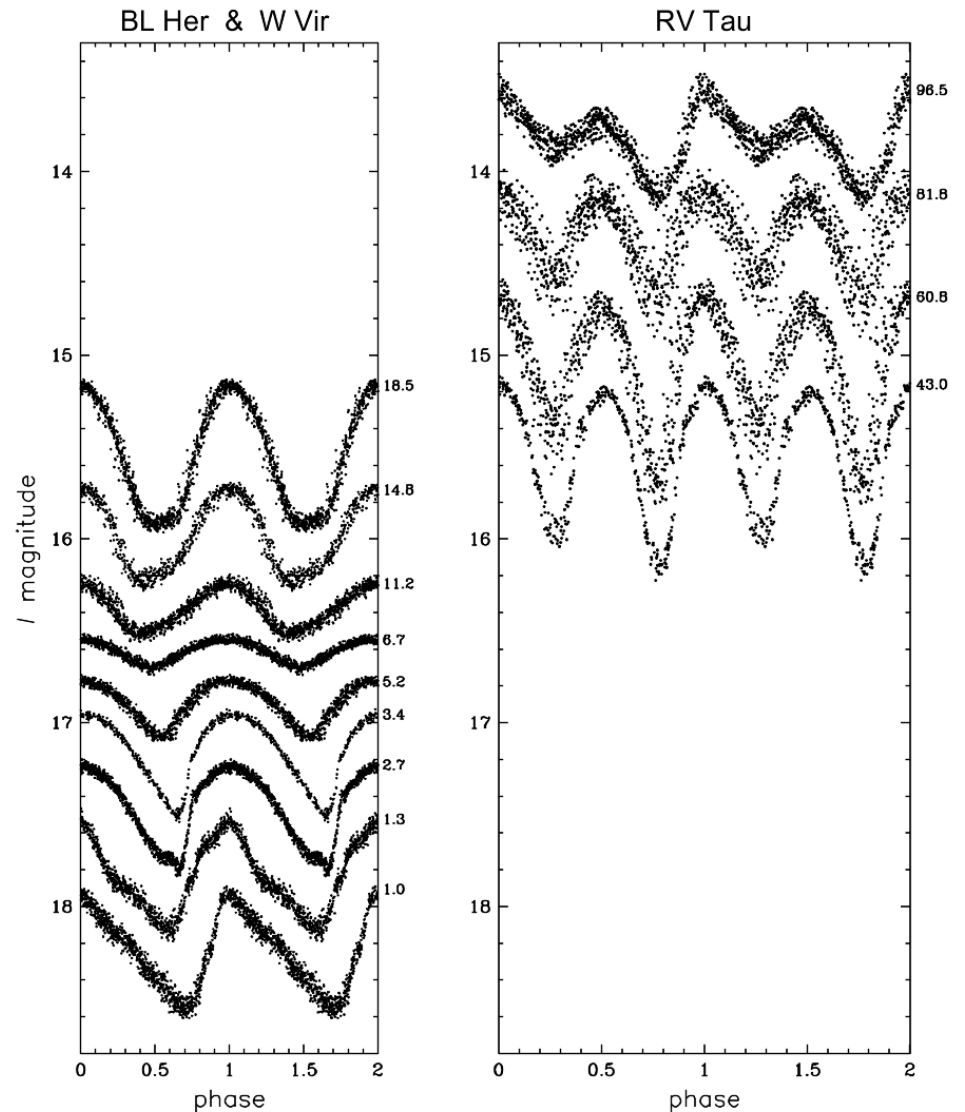


Type II Cepheids

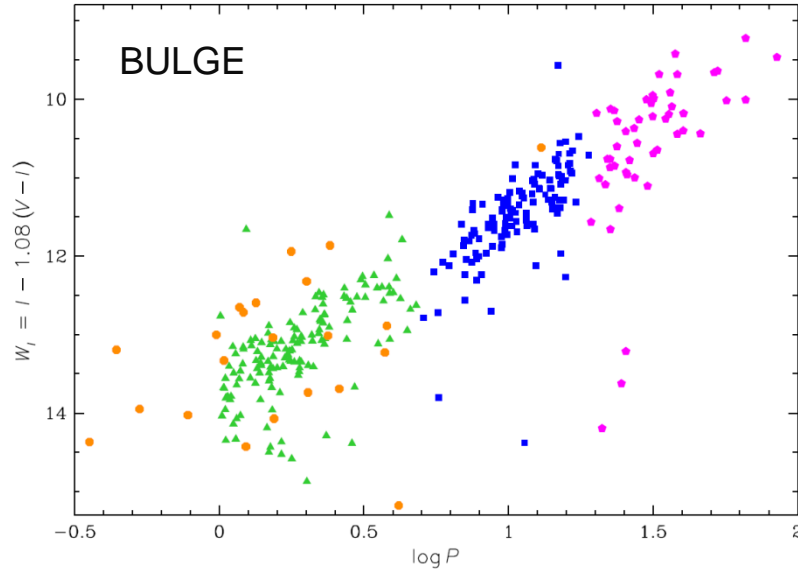
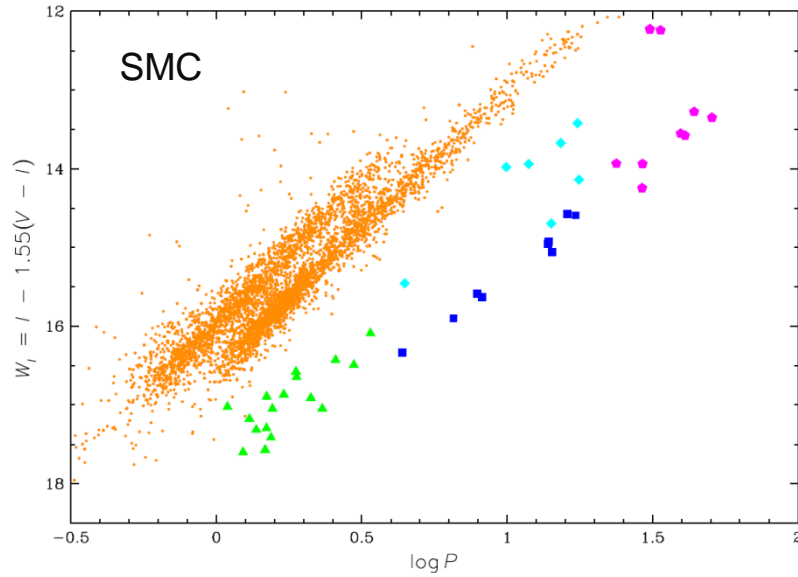
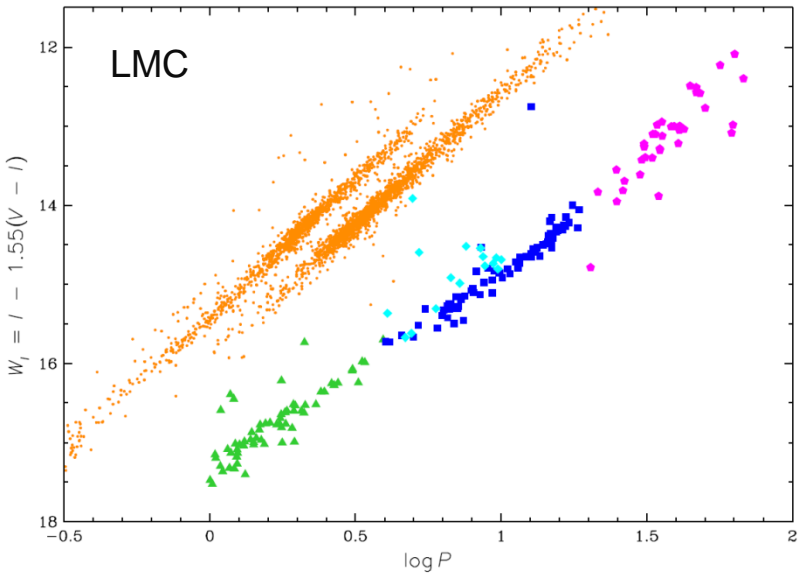
LMC: 203 objects

SMC: 43 objects

GB: 335 objects



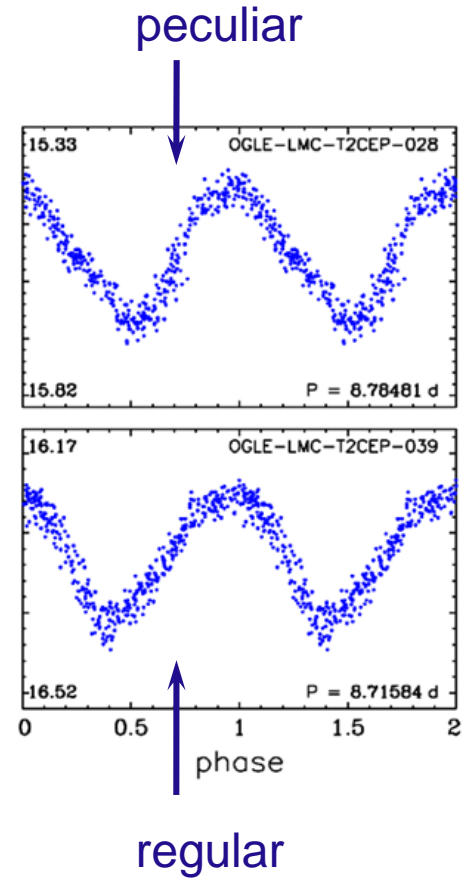
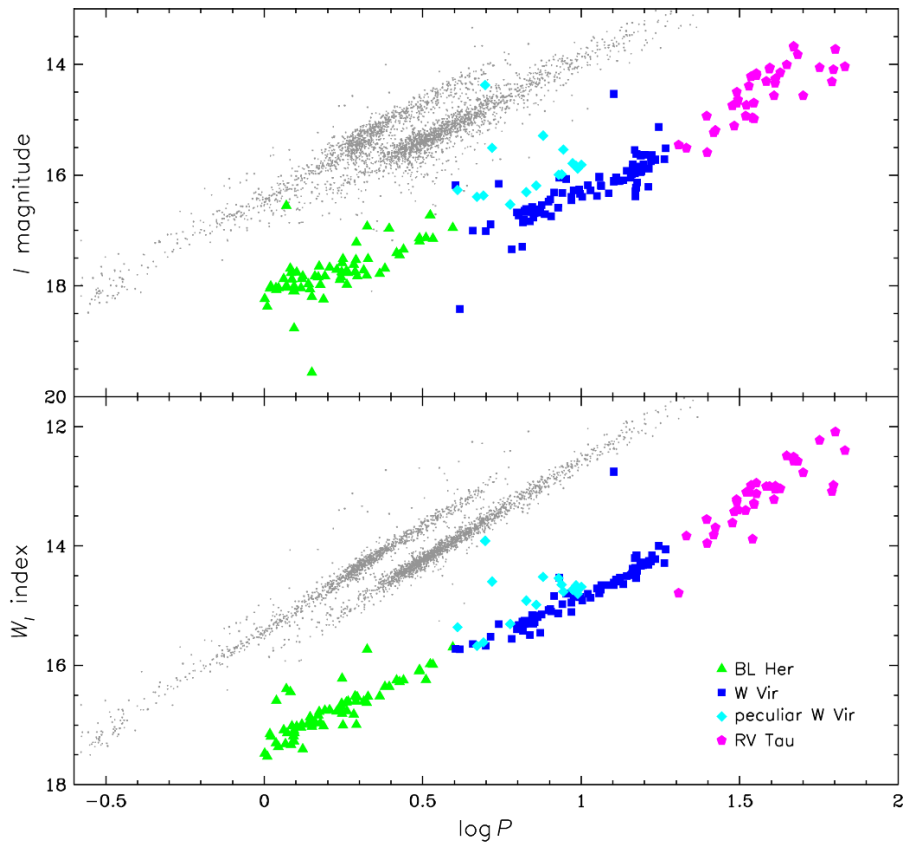
Type II Cepheids



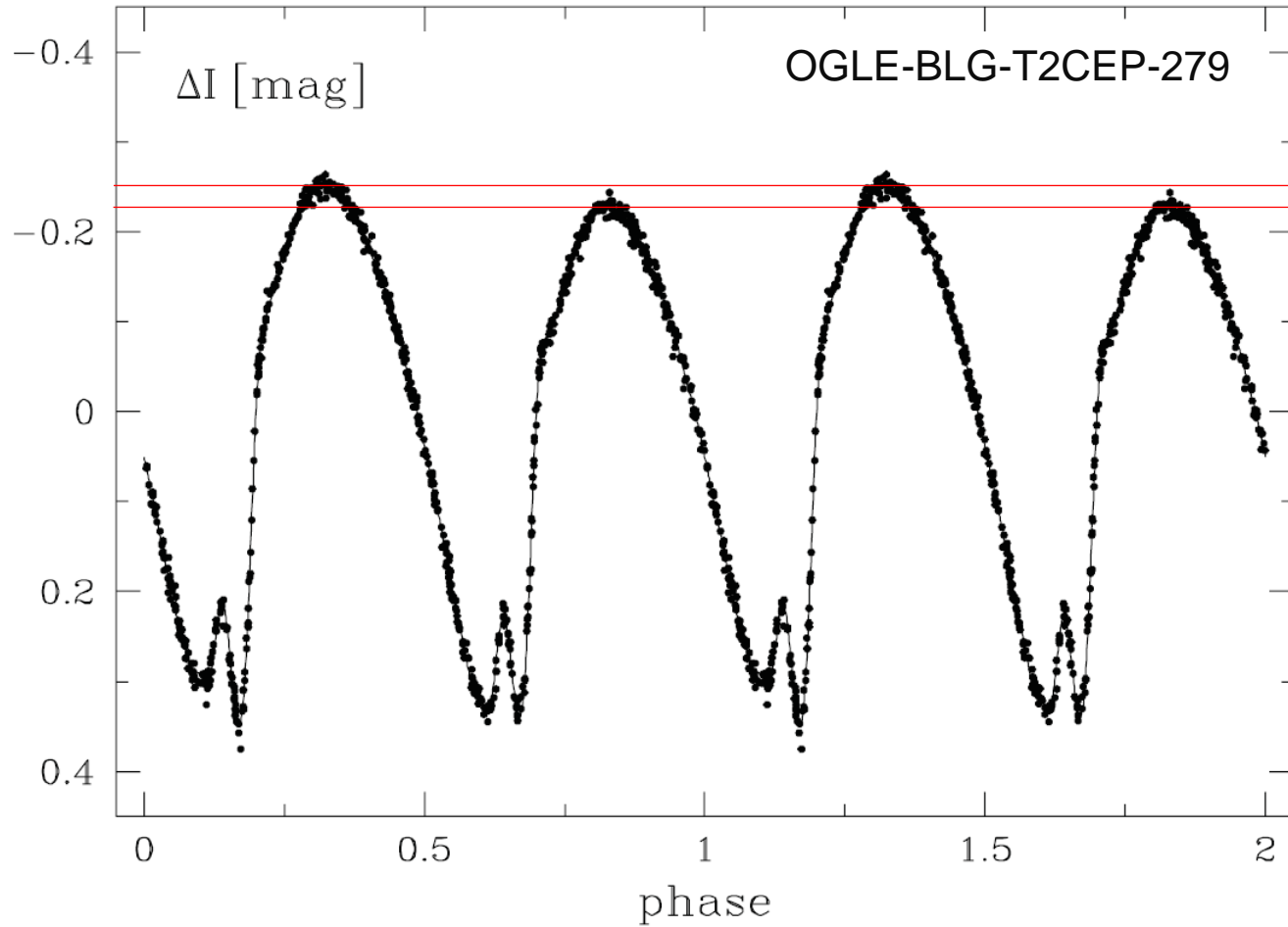
- classical Cepheids
- ▲ BL Herculis
- W Virginis
- ◆ peculiar W Virginis
- ◆ RV Tauri

Type II Cepheids

New subtype of type II Cepheids:
peculiar W Virginis stars



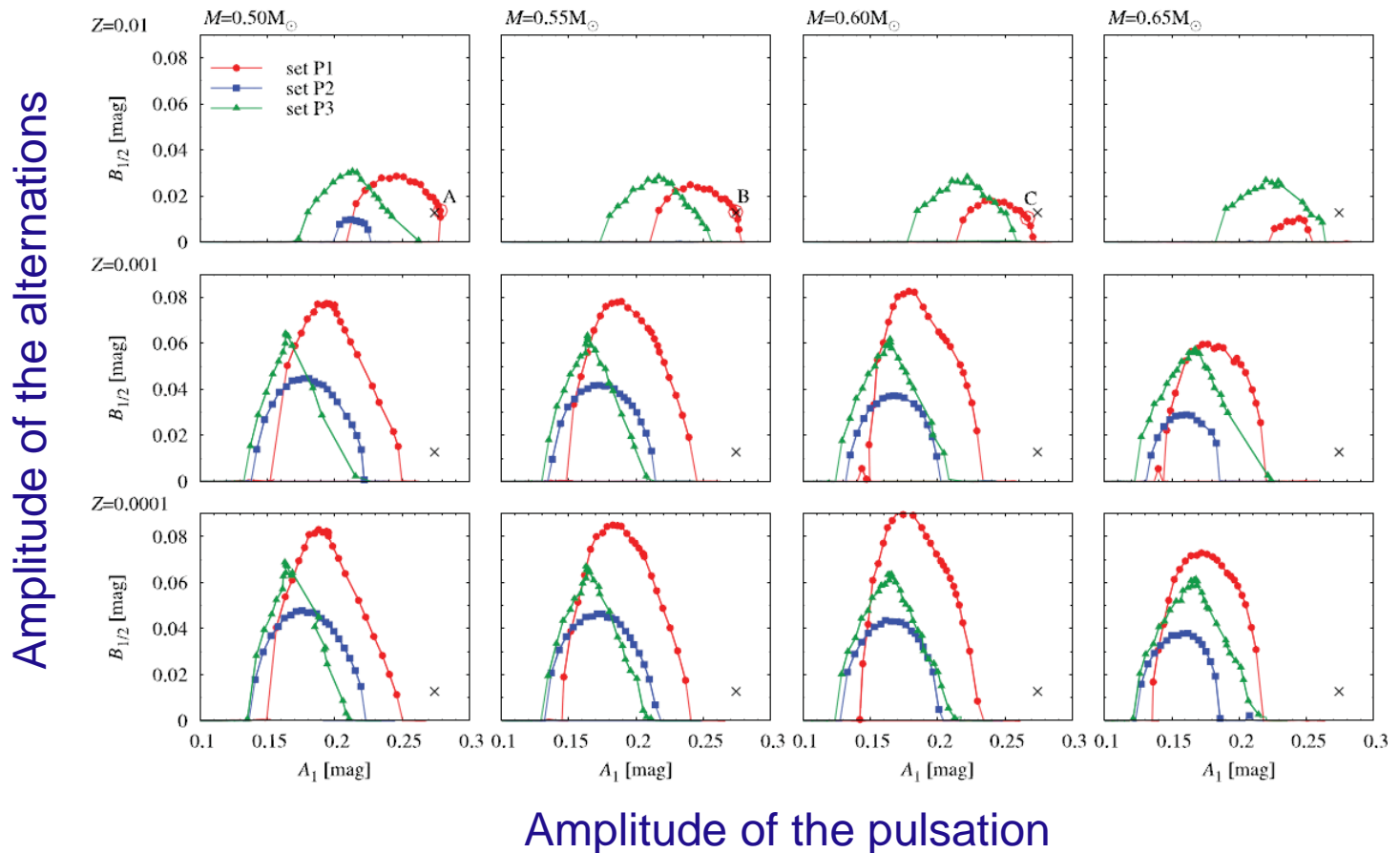
Period doubling in BL Her stars



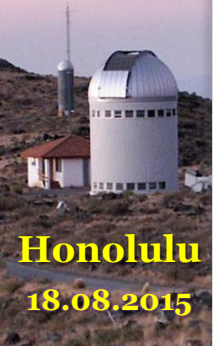
Period doubling in BL Her stars

Smolec et al. (2011)

3:2 resonance between the fundamental and first overtone modes

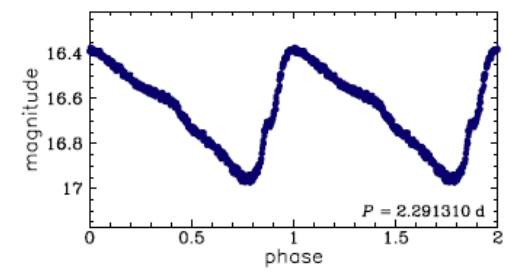
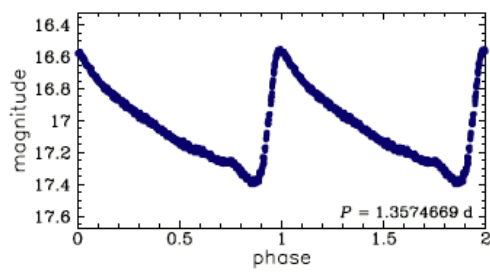
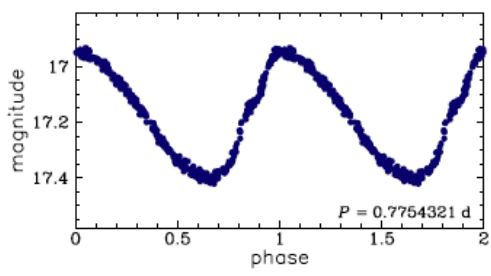


ANOMALOUS CEPHEIDS



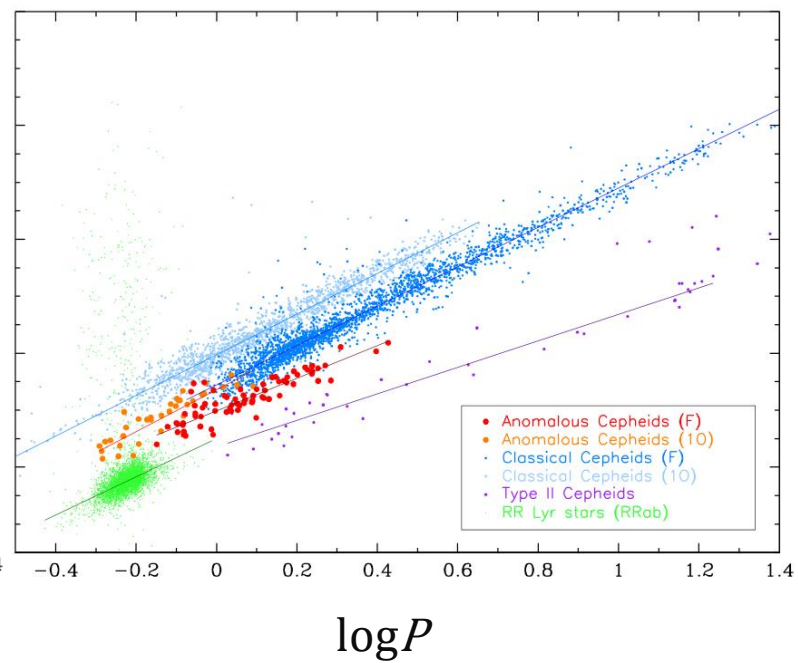
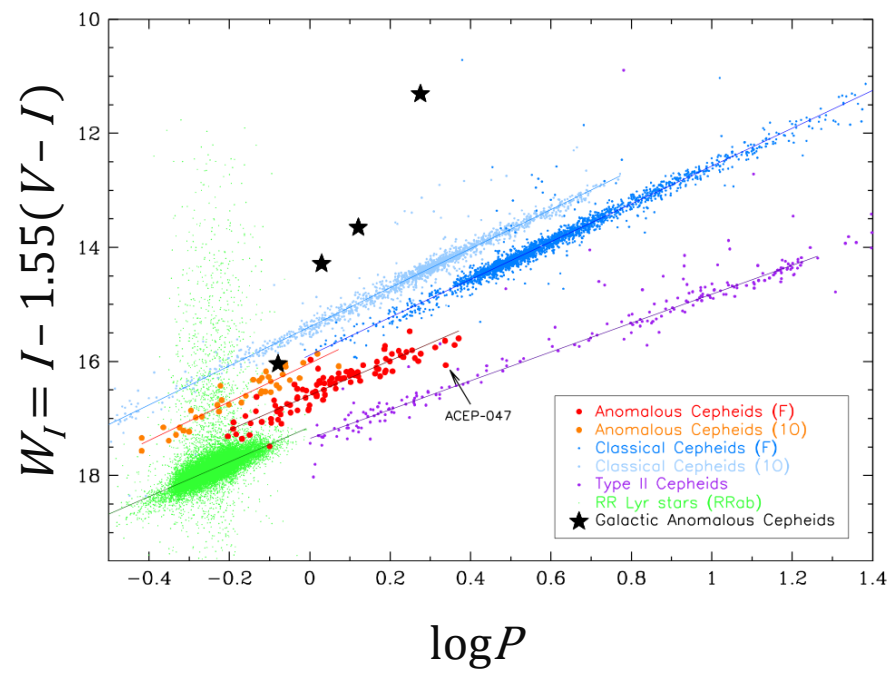
Anomalous Cepheids in the MC

250 objects

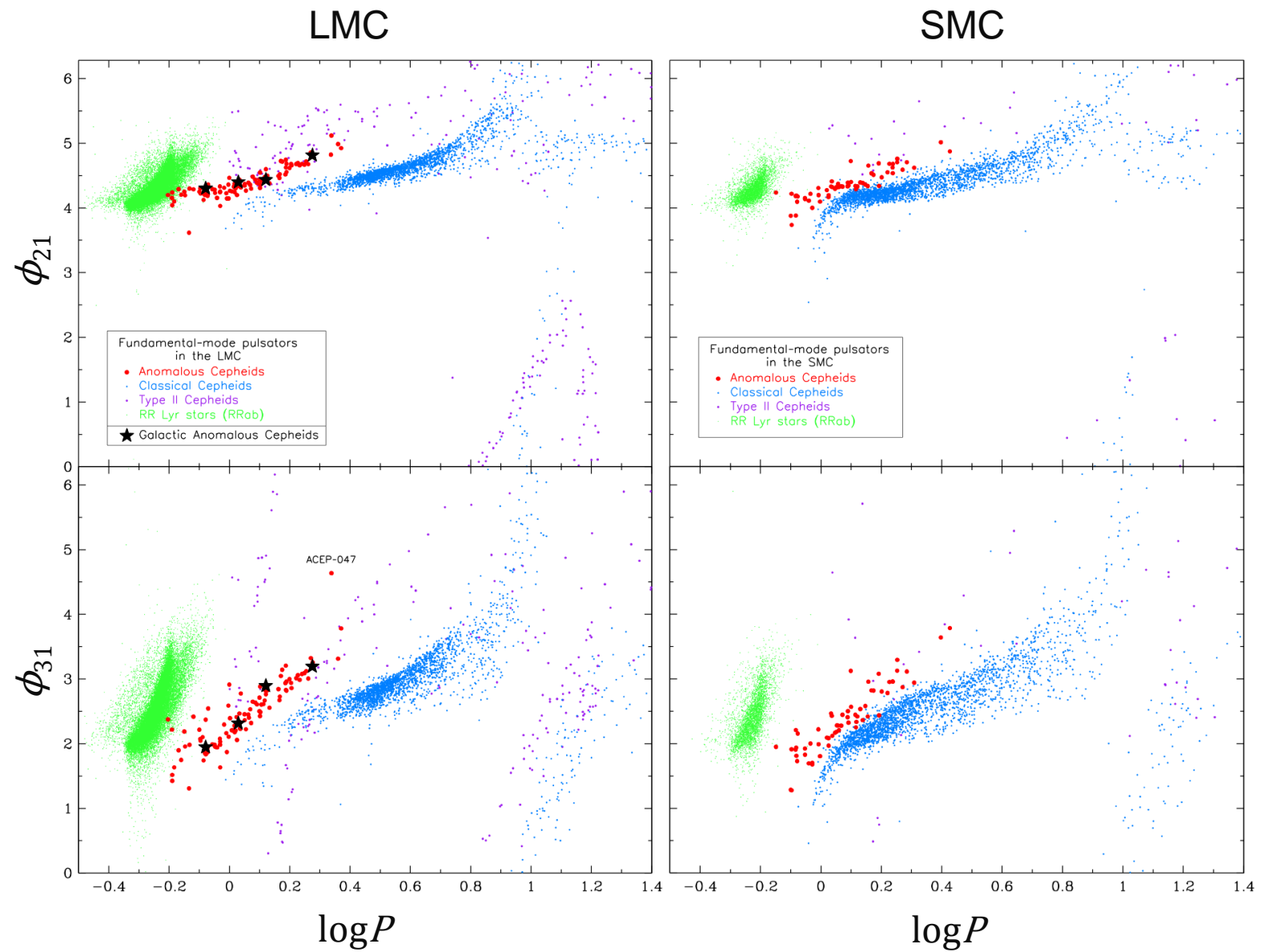


LMC

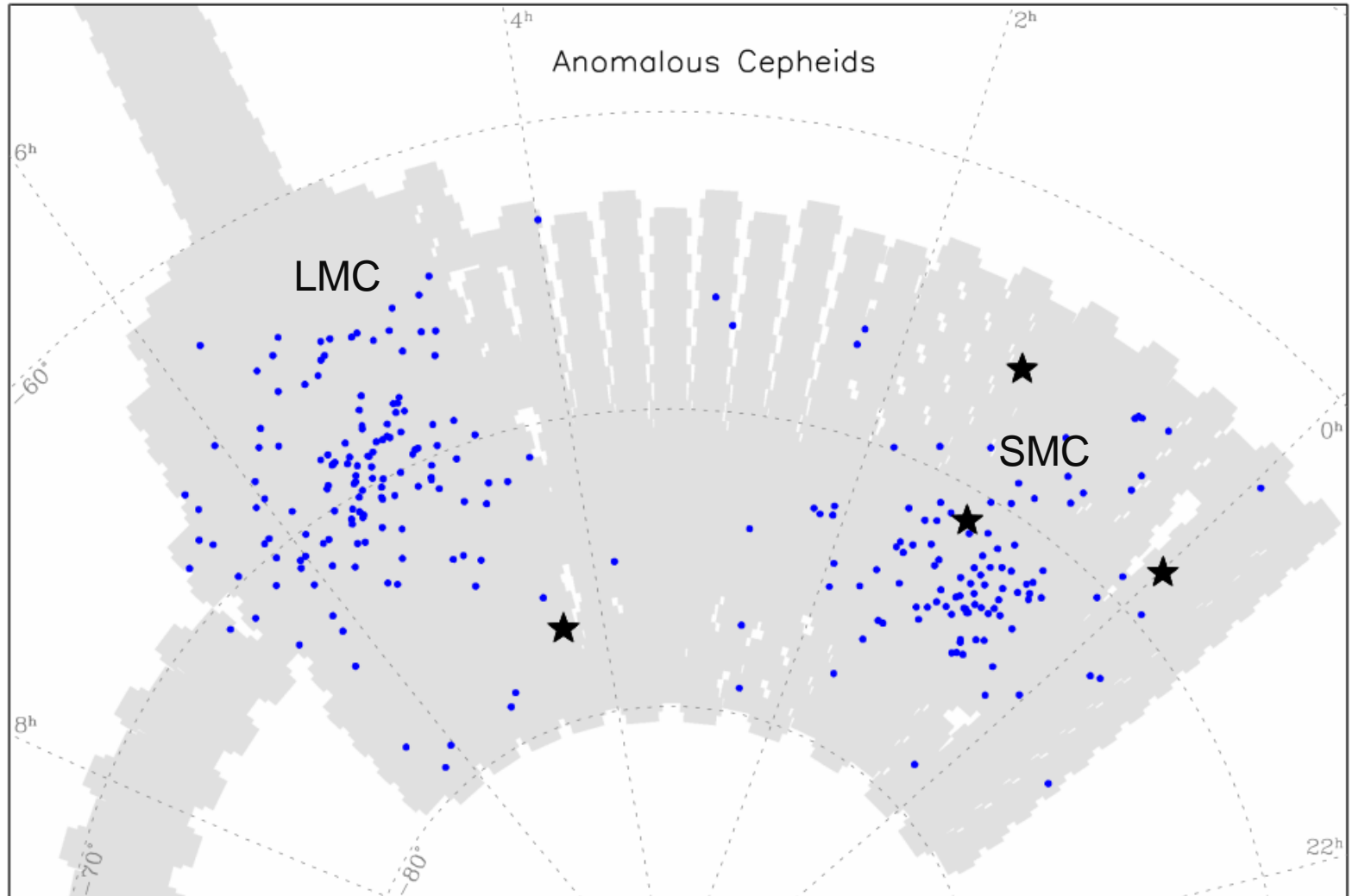
SMC



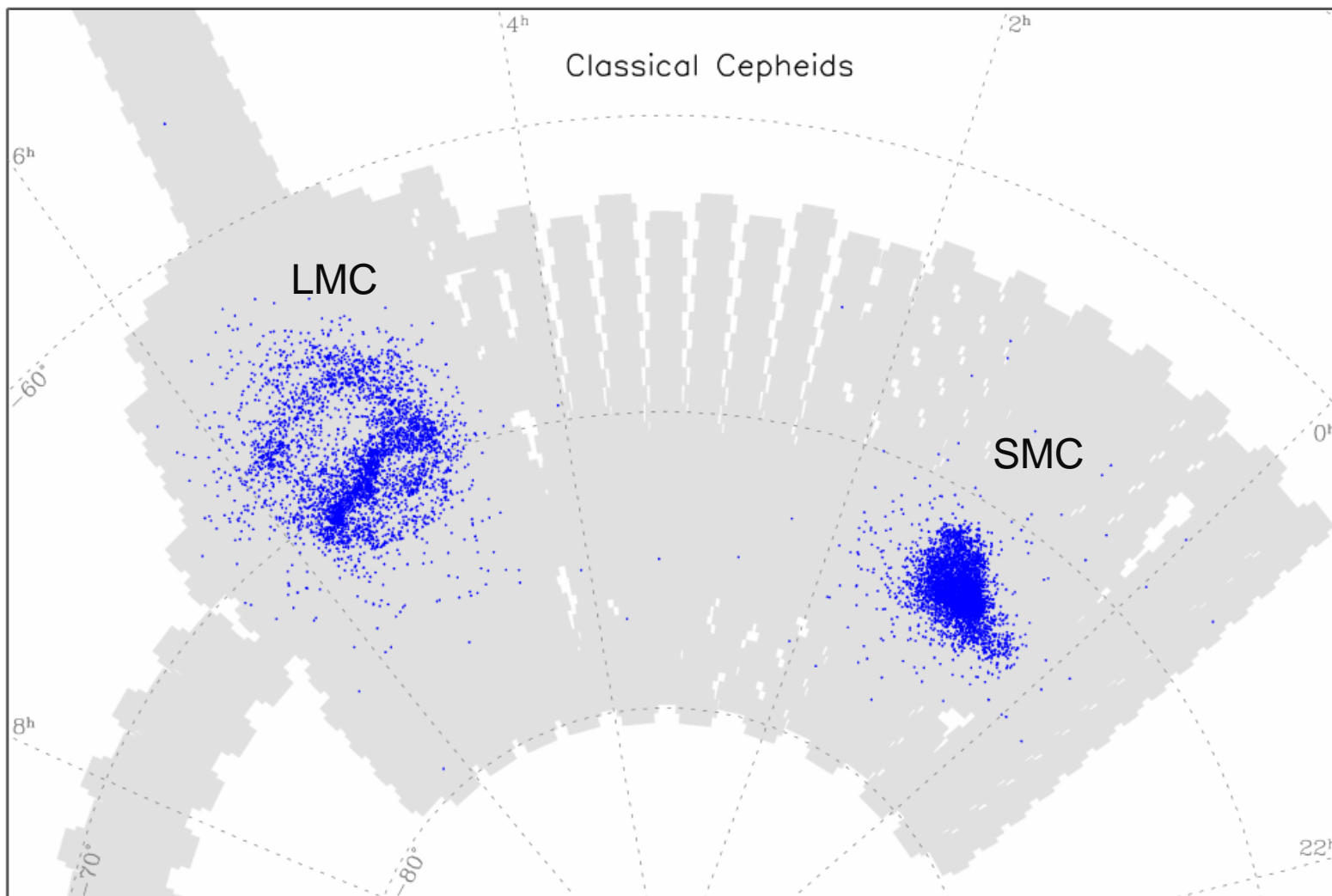
Anomalous Cepheids in the MC



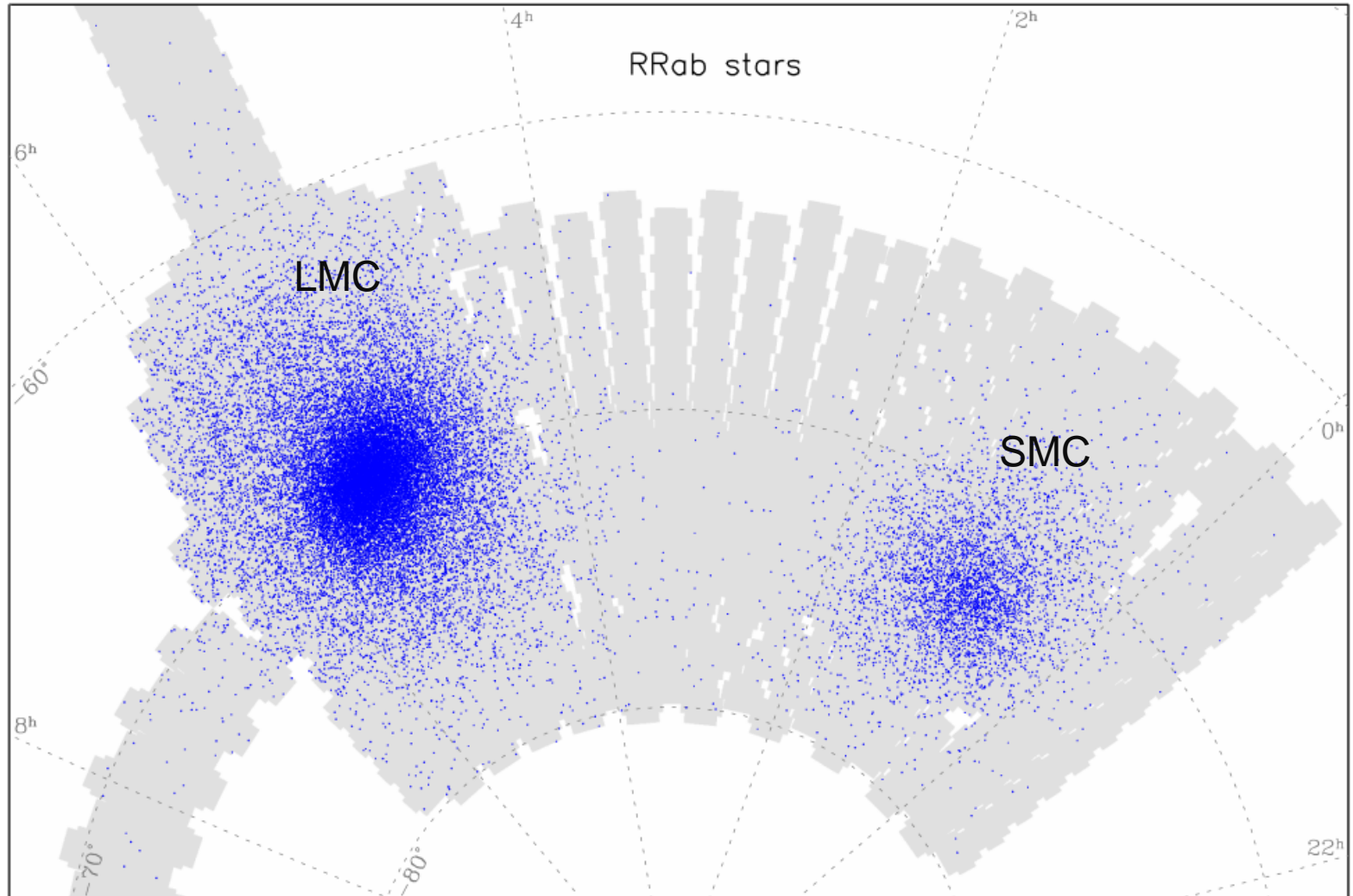
Anomalous Cepheids in the MC



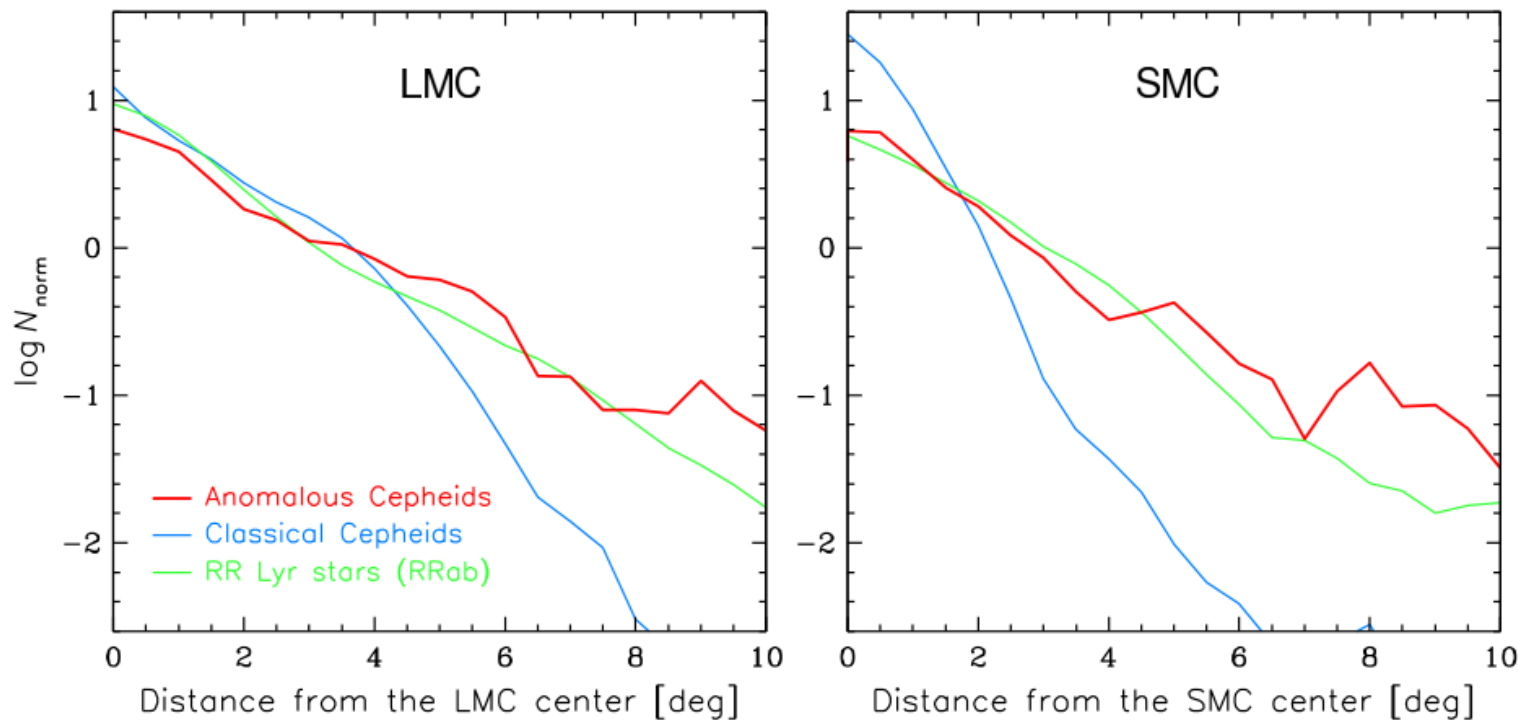
Classical Cepheids in the MC



RR Lyrae stars in the MC



Anomalous Cepheids in the MC



LONG-PERIOD VARIABLES

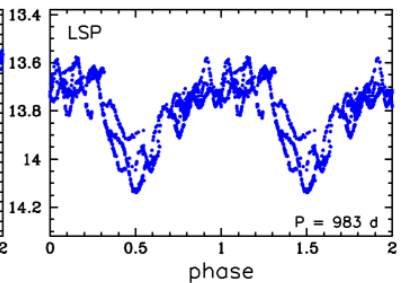
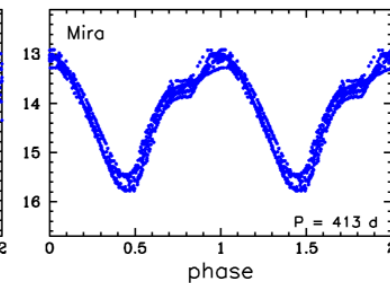
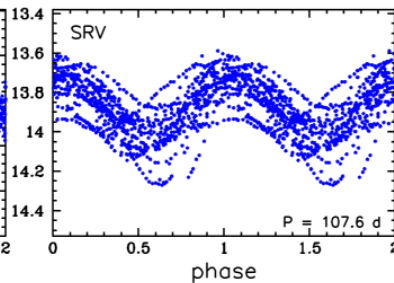
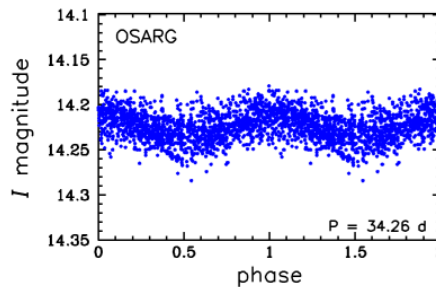
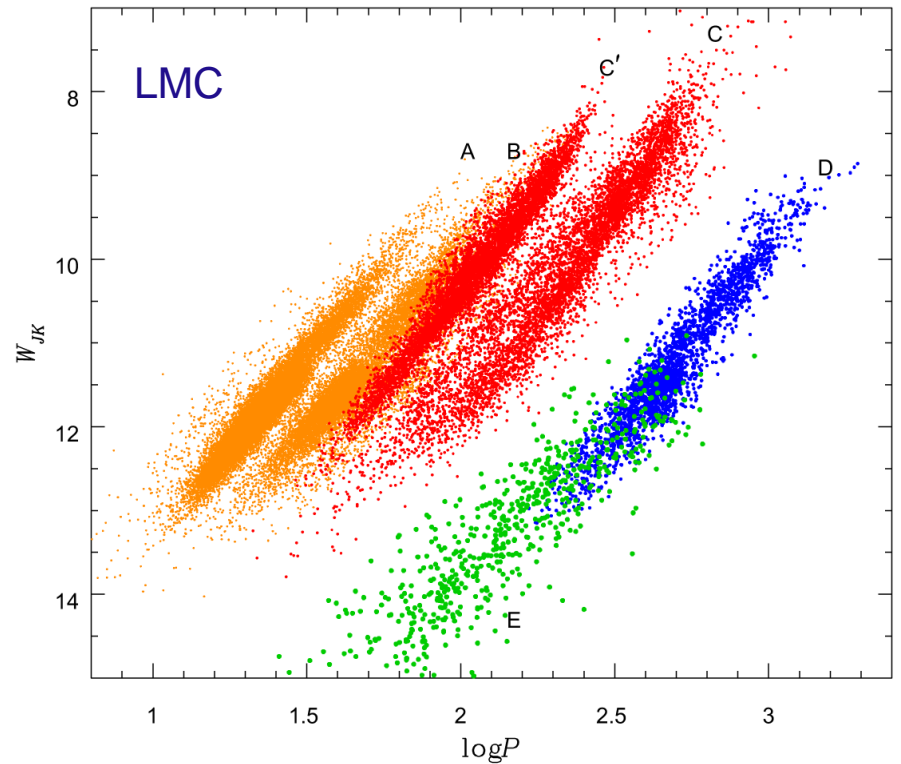


Long-Period Variables

LMC: 91 995 objects

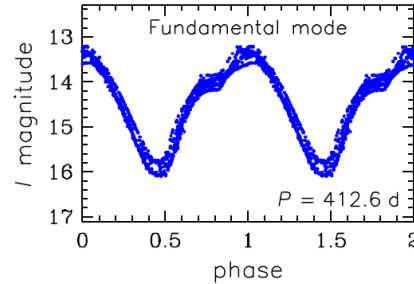
SMC: 19 384 objects

GB: 232 835 objects

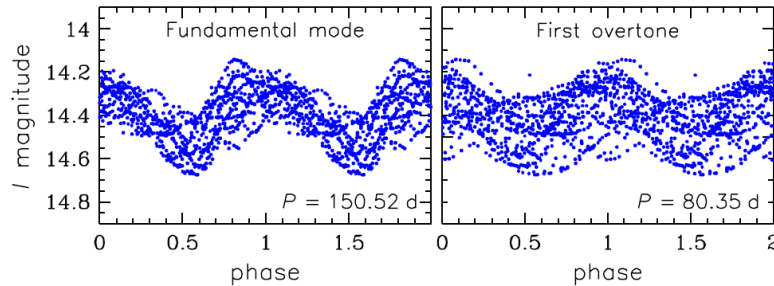


Long-Period Variables

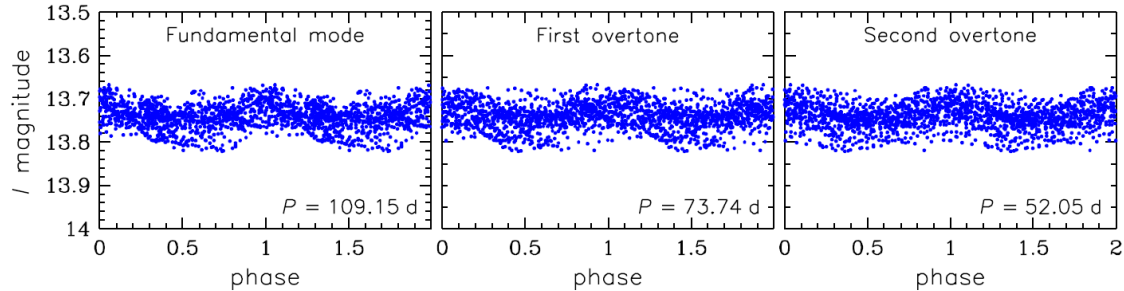
- Miras



- Semiregular Variables (SRVs)

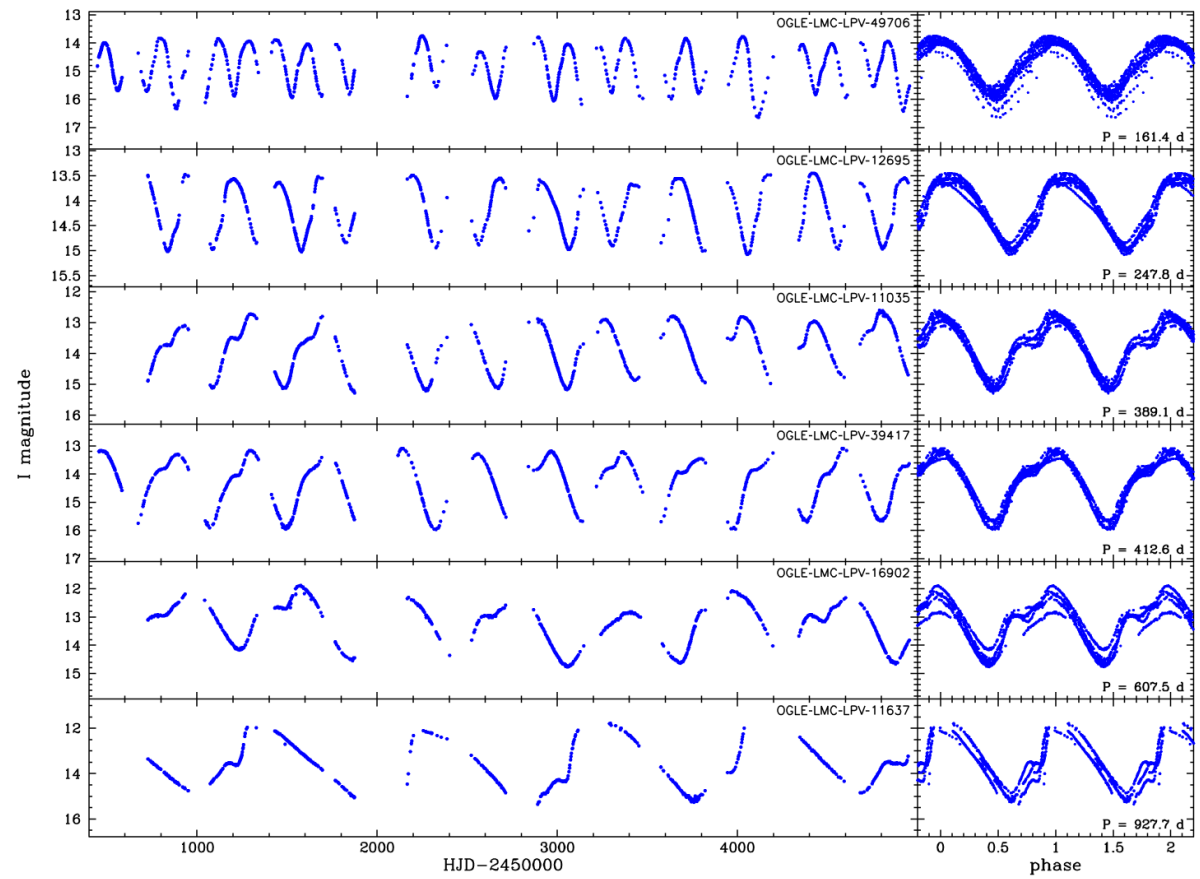
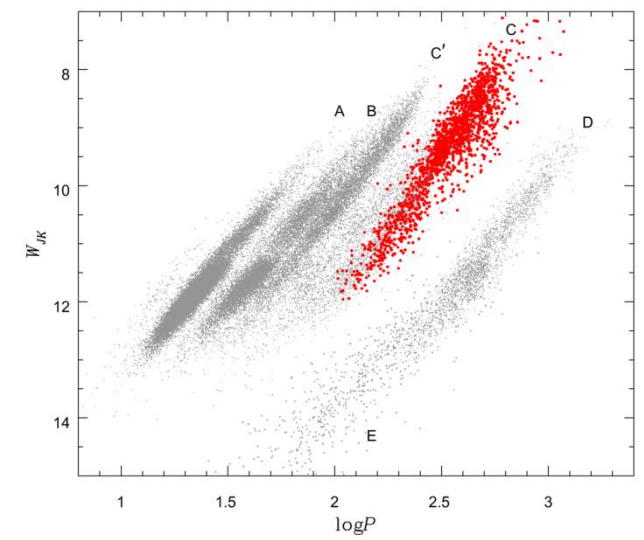


- OGLE Small Amplitude Red Giants (OSARGs)



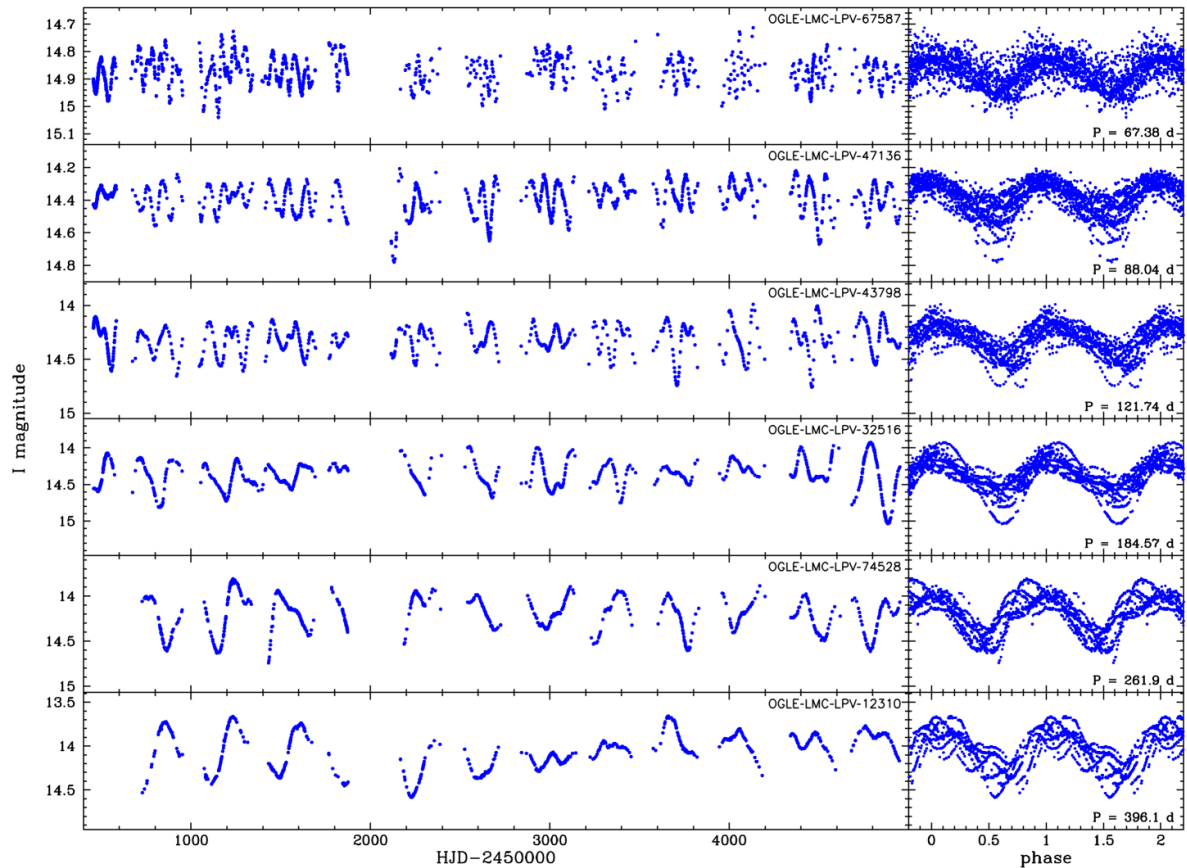
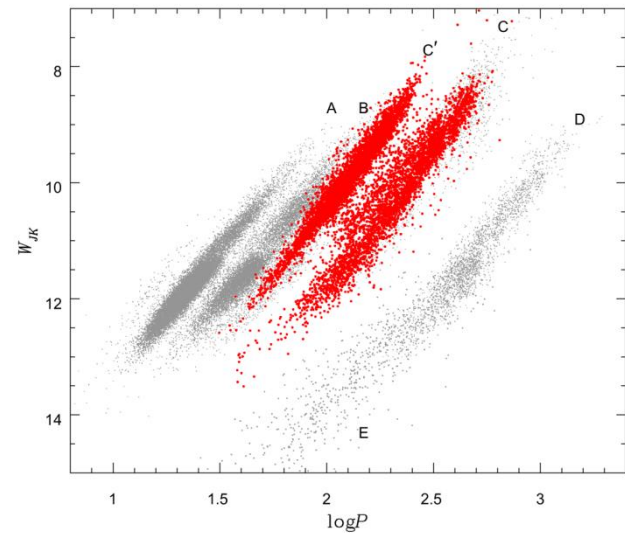
Miras

Sequence C



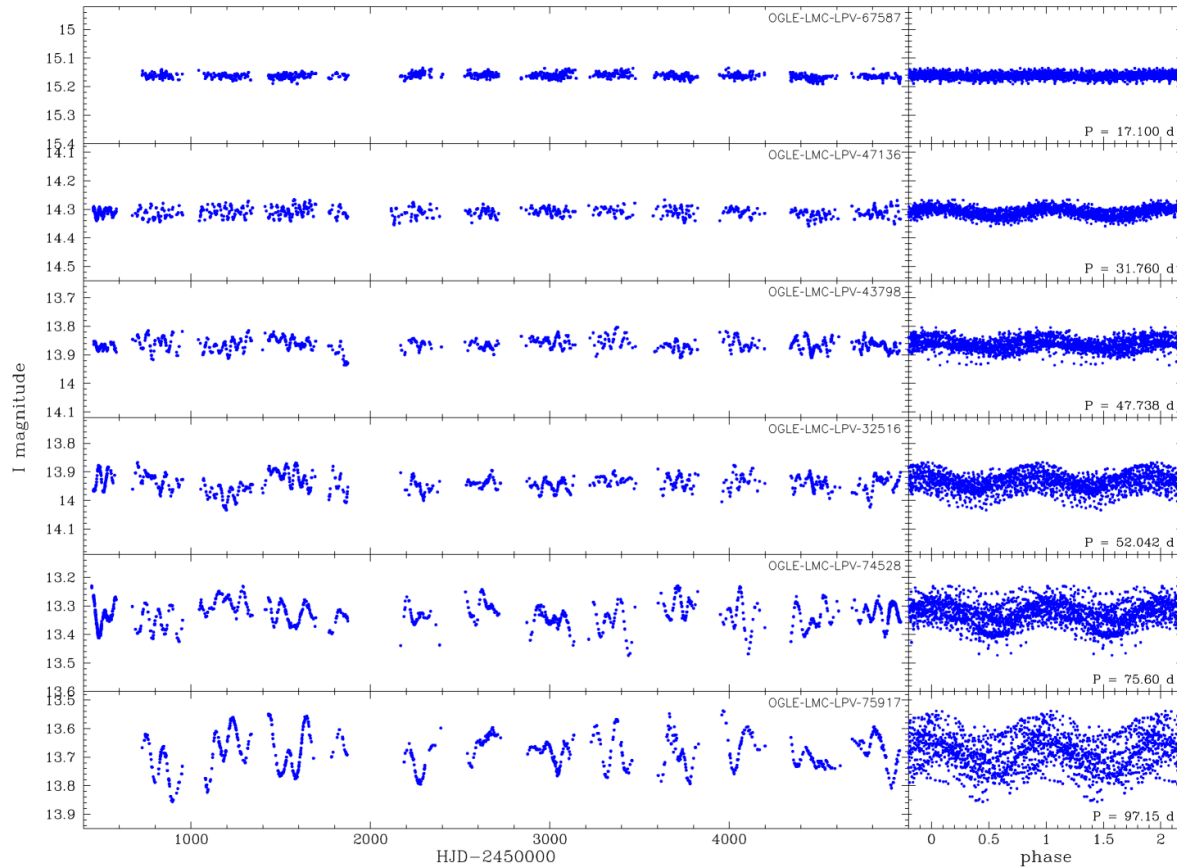
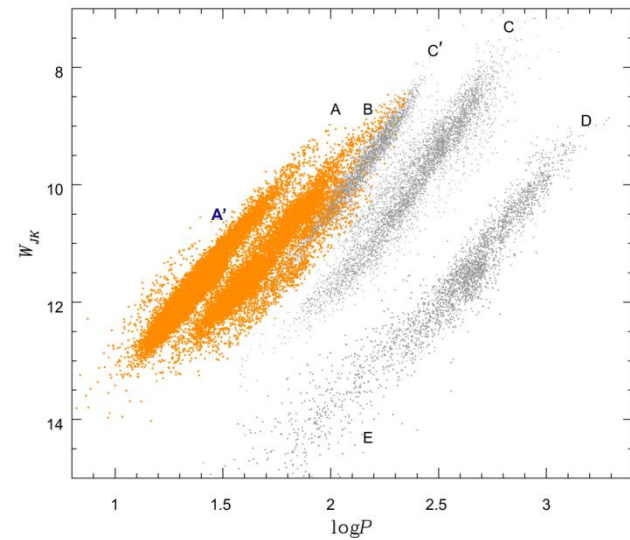
Semiregular Variables (SRV)

Sequences C and C'

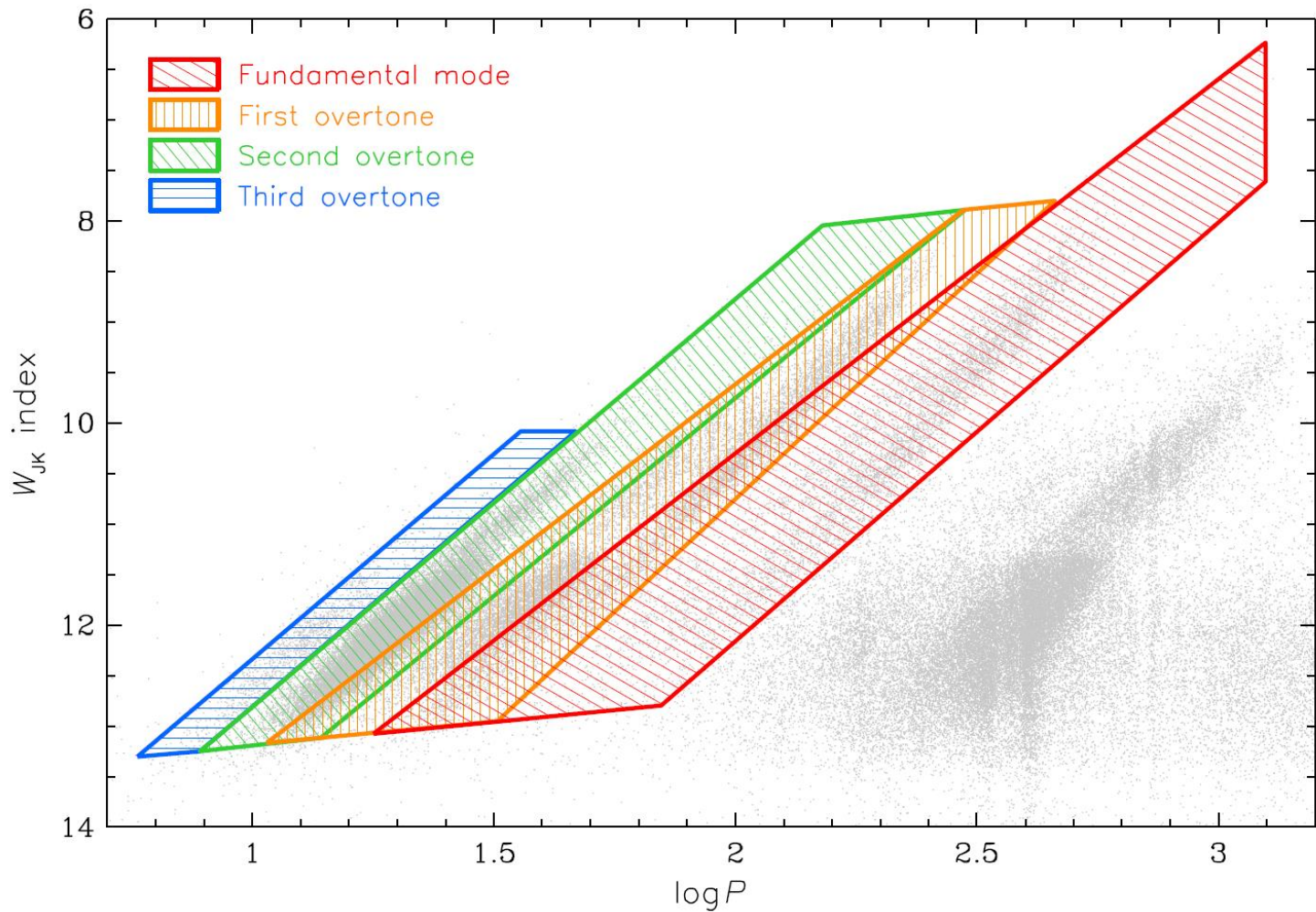


OGLE Small Amplitude Red Giants (OSARG)

Sequences **A**, **B** and others



Pulsation modes in the PL plane



Soszyński et al. (2013)

Long-Period Variables

