OGLE-ing the Magellanic System

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with the OGLE Team

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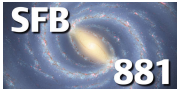

A synoptic view of the Magellanic Clouds
ESO, Garching bei München, 12.09.2019

OGLE-ing the Magellanic System

1. The OGLE project: introduction and motivation
2. Classical pulsators in the Magellanic Clouds
3. Classical pulsators in the Magellanic Bridge
4. Conclusions

Optical Gravitational Lensing Experiment (OGLE)

ogle.astrouw.edu.pl

Photo by Y. Beletsky.

- ⋆ Largest polish astronomical project
- ⋆ Since 1992
- ⋆ 1.3-m Warsaw Telescope in Chile, Las Campanas

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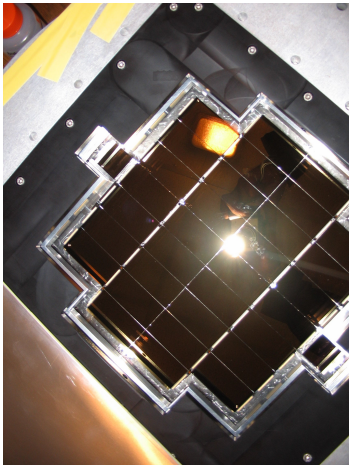

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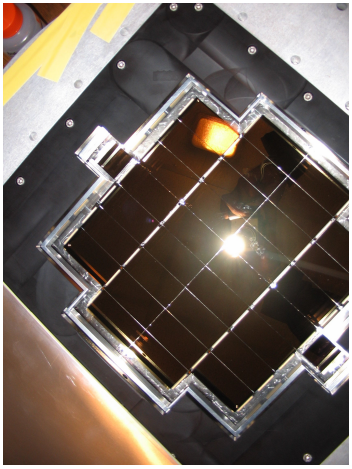

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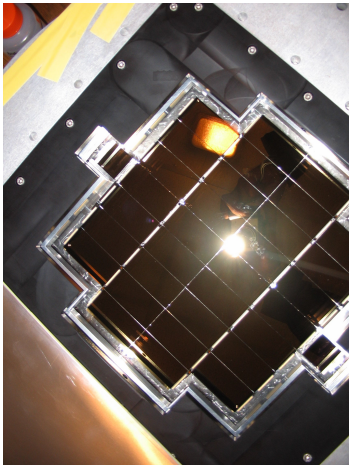

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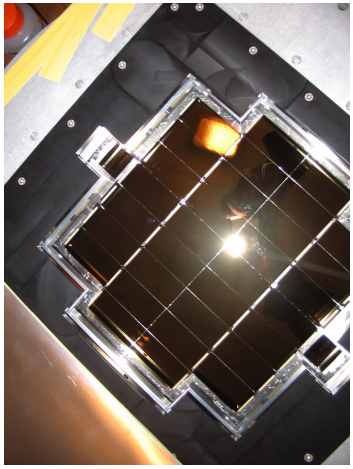

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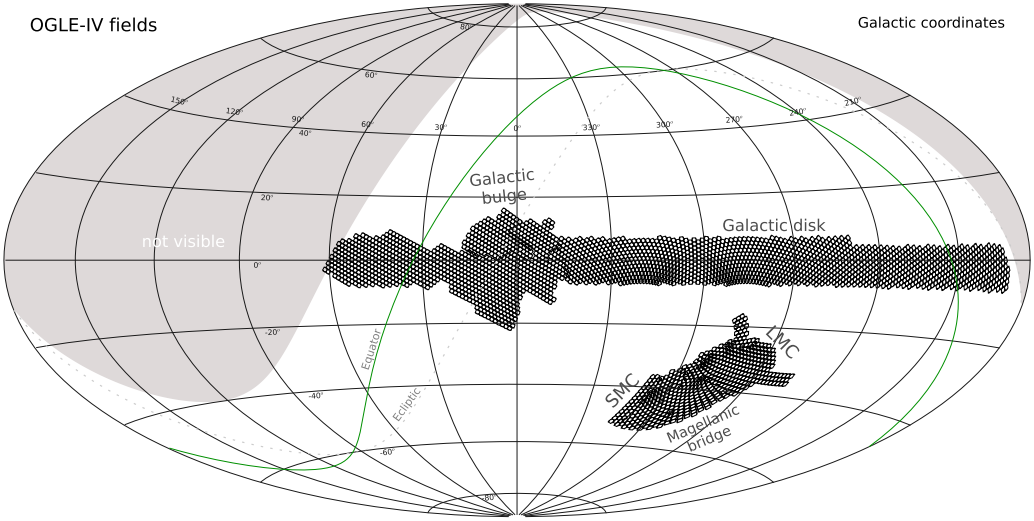
- Sky coverage: 3600 deg^2
- Every night monitors 2 billion sources
- Largest collection of variable stars: $\sim$1 million objects

OGLE-IV fields (as of August 2018)



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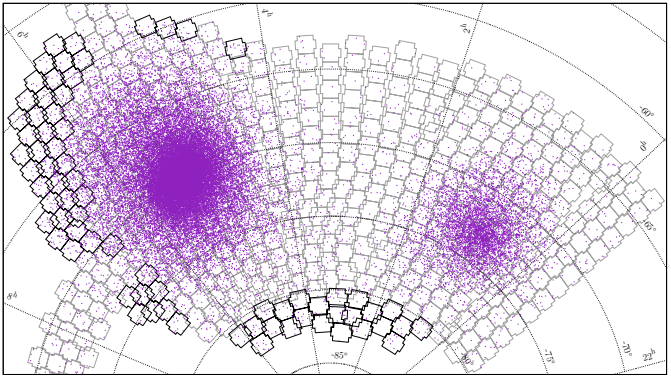
OGLE and the Magellanic System



AJD et al. (2019b), Soszyński et al. (2019)

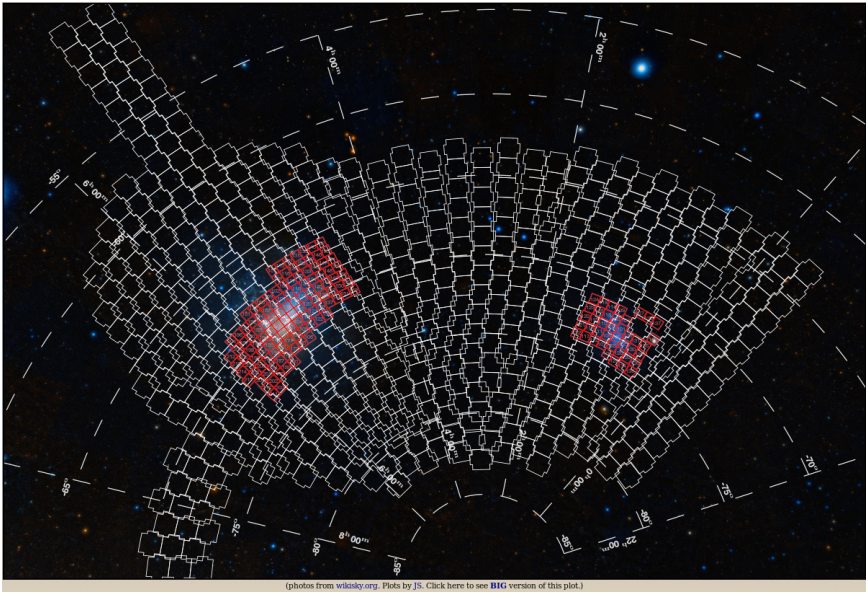
- Sky coverage: 765 sq. deg. (544 fields).
- OGLE Collection of Variable Stars (OCVS):
  - 9650 classical Cepheids,
  - 343 type II Cepheids,
  - 278 anomalous Cepheids,
  - 47 828 RR Lyrae stars.
- *OGLE-ing the Magellanic System* series of papers.

Aims of our study

Our main goals:

- First analysis of 3d structure of the Magellanic System using OGLE-IV data *(Soszyński et al. 2015, 2016, 2017, 2019)*.

OGLE-III and OGLE-IV fields



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Aims of our study

Our main goals:

- Analyze 3d structure of the Magellanic System using OGLE-IV data *(Soszyński et al. 2015, 2016, 2017, 2019)*.
- Search for any evidence of a RR Lyrae Bridge *(Belokurov et al. 2017)*.

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Why was it worth the effort?

1. Vast sky coverage of the OGLE-IV in the Magellanic System combined with very accurate photometry and high cadence → OCVS is a perfect database to study 3d structure of the MS.

Aims of our study

Our main goals:

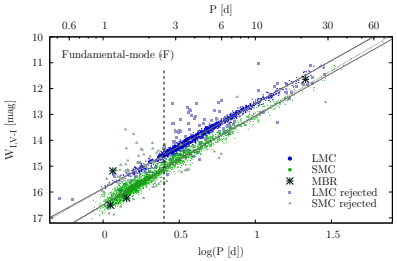
- Analyze 3d structure of the Magellanic System using OGLE-IV data *(Soszyński et al. 2015, 2016, 2017, 2019)*.
- Search for any evidence of a RR Lyrae Bridge *(Belokurov et al. 2017)*.

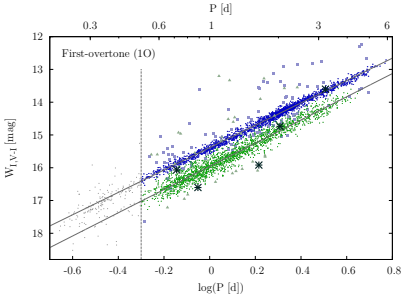
Why was it worth the effort?

1. Vast sky coverage of the OGLE-IV in the Magellanic System combined with very accurate photometry and high cadence → OCVS is a perfect database to study 3d structure of the MS.
2. The Magellanic System is our "local laboratory" in the context of interacting galaxies.

Classical pulsators in the Magellanic Clouds

Classical Cepheids: period–luminosity relations





AJD et al. (2016)

- Over 9000 CCs (F+1O).

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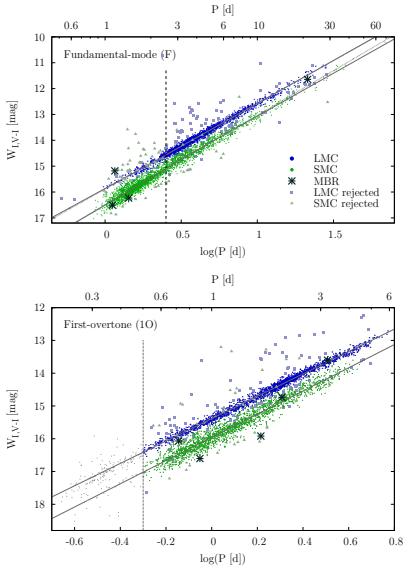
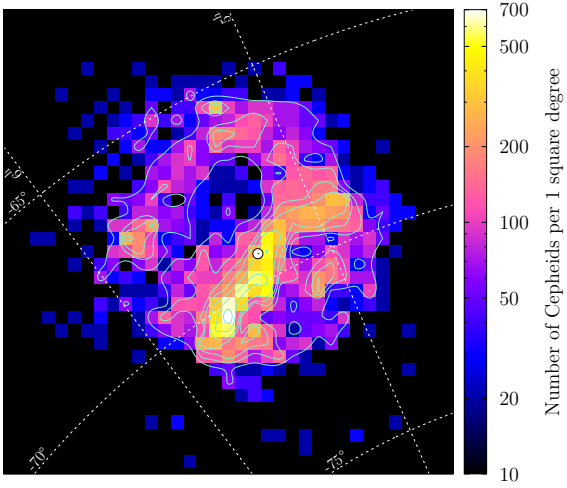


AJD et al. (2016)

- Over 9000 CCs (F+1O).
- The fitted line in the LMC corresponds to its mean distance *(Pietrzyński et al. 2013)*.

LMC: classical Cepheids



AJD et al. (2016)

- CCs clumped in structures.

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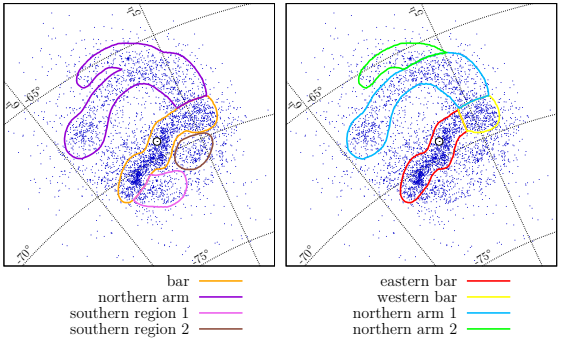

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- CCs clumped in structures.
- Redefinition of the bar (western part added).

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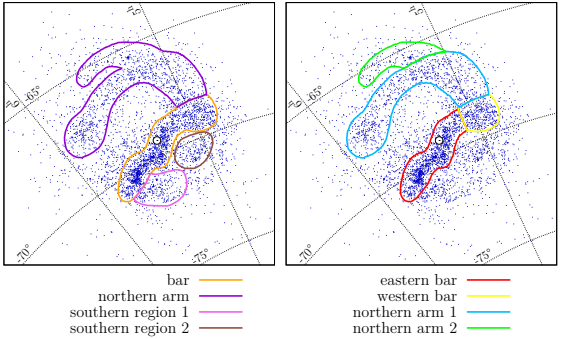

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- Additional smaller northern arm located north most (already reported by *Besla et al. 2016*).

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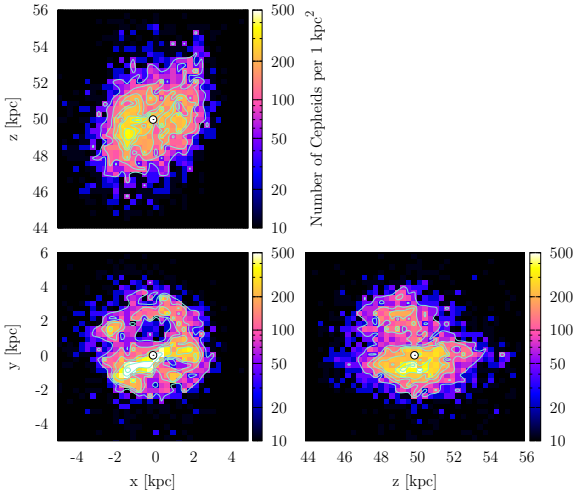

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- The new bar in the mean LMC distance. Dynamical center in the center of the bar.

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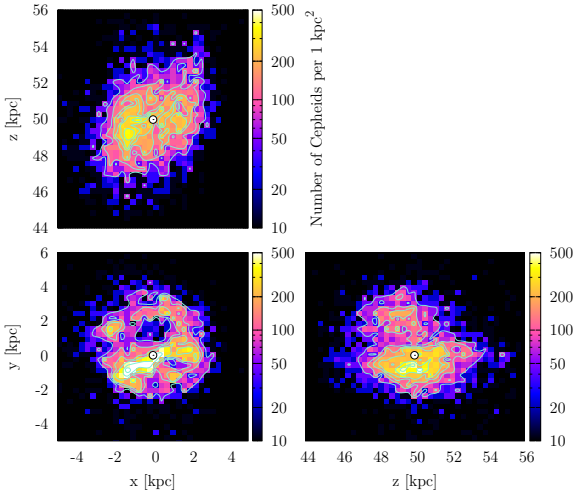

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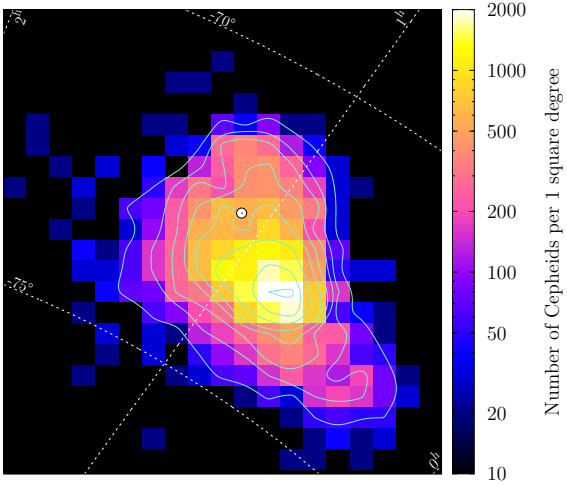
- Additional smaller northern arm located north most (already reported by *Besla et al. 2016*).
- The new bar in the mean LMC distance. Dynamical center in the center of the bar.
- The northern arm located closer (~ 0.5 kpc).

SMC: classical Cepheids



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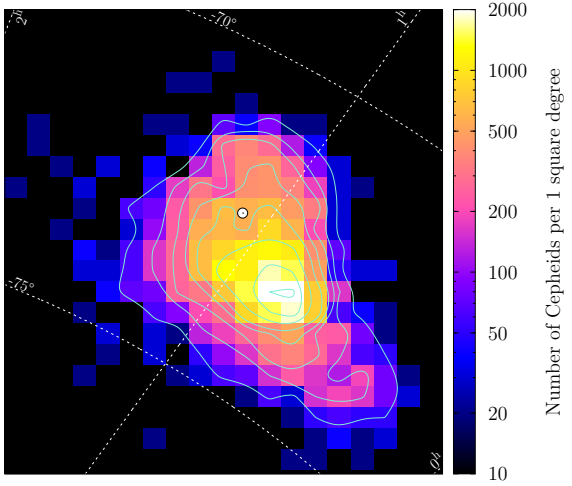

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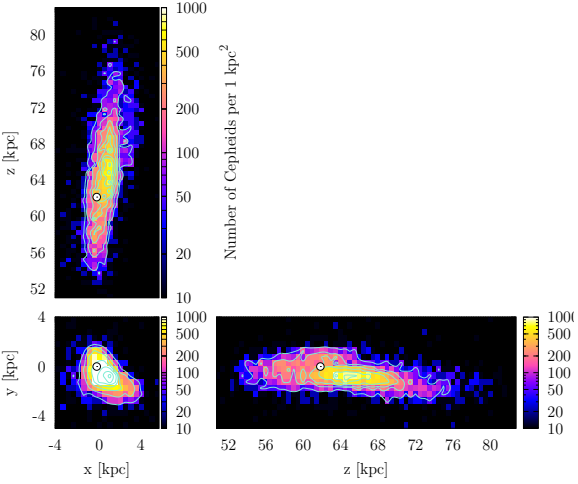

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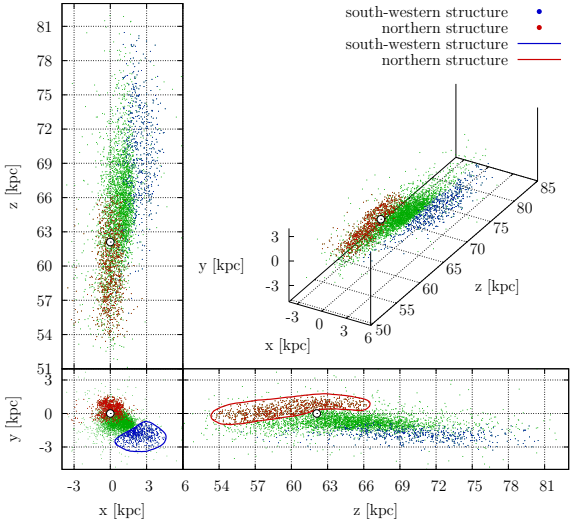

AJD et al. (2016)

- Ellipsoid elongated almost along the *los*.
- Two ellipsoidal off-axis substructures.

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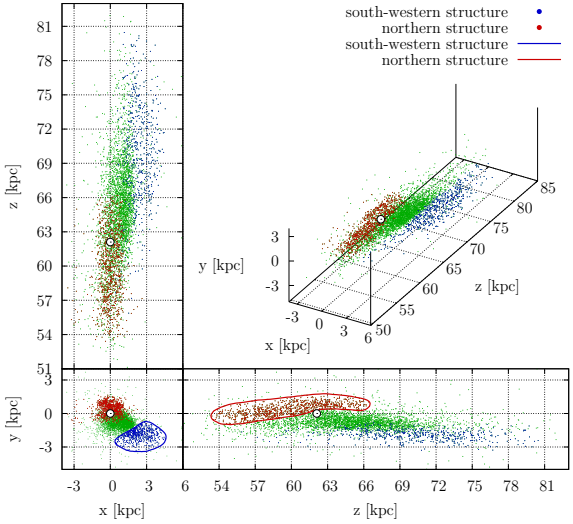


AJD et al. (2016)

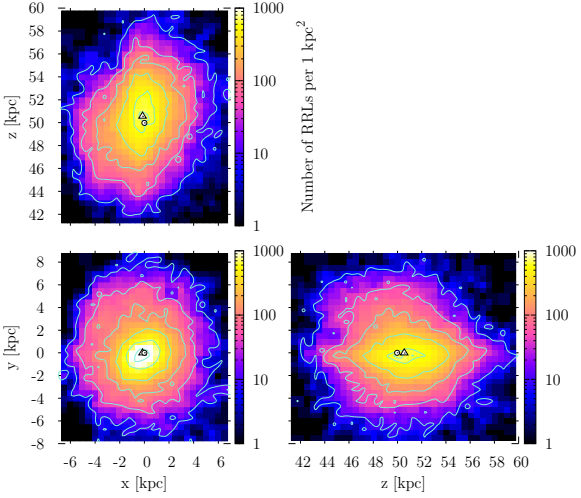
- Ellipsoid elongated almost along the *los*.
- Two ellipsoidal off-axis substructures.
- CCs closer to us are younger, farther – older.

RR Lyrae stars: photometric metallicities

1. Photometric metallicity + period → absolute magnitude *(Braga et al. 2015)*.
2. Absolute magnitude + apparent magnitude → distance.

Our sample consists of almost 23000 RRL stars.

LMC: RR Lyrae stars



AJD et al. (2017)

- Very regular structure.

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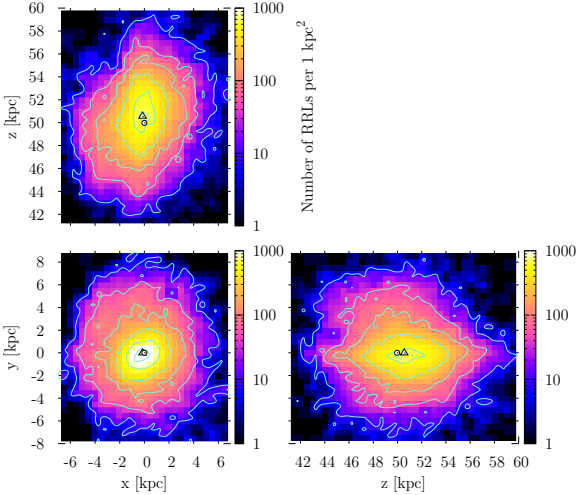

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- Very regular structure.
- Non-physical "blend-artifact" (crowding and blending).

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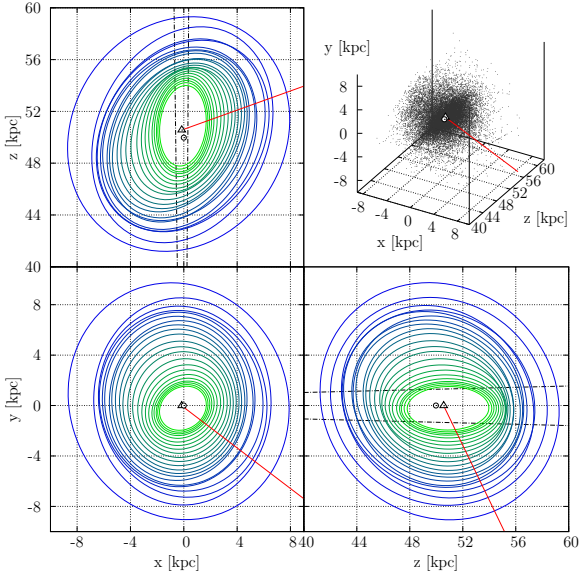

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- Triaxial ellipsoids fitted.

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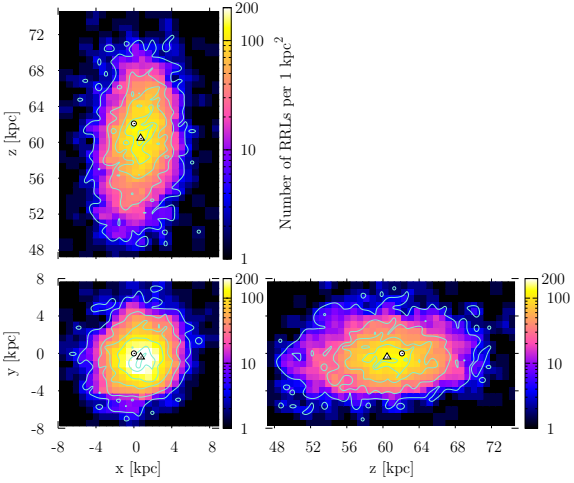

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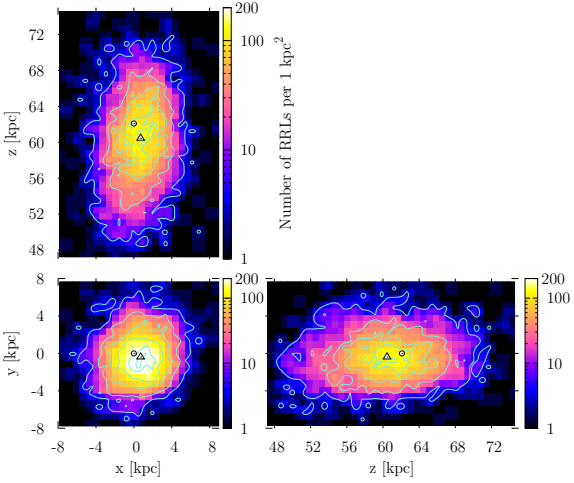

AJD et al. (2017)

- Very regular structure.
- No additional features.

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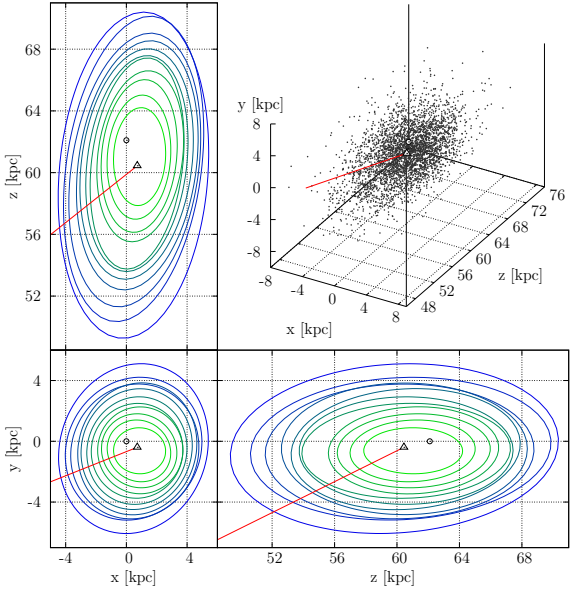

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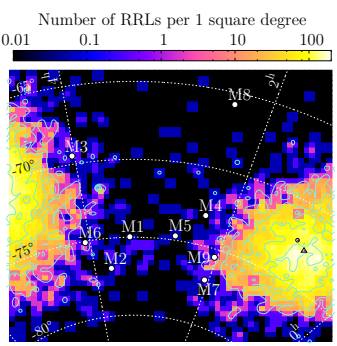
Classical pulsators in the Magellanic Bridge

RR Lyrae stars in the Magellanic Bridge



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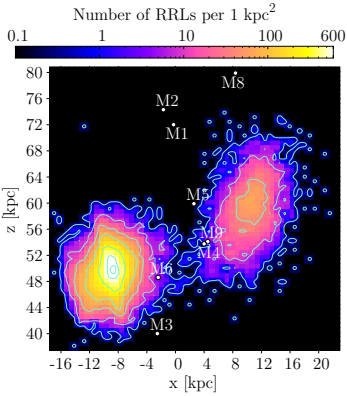
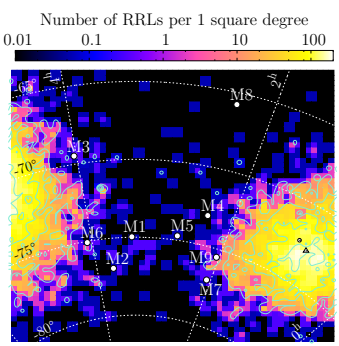


AJD et al. (2017)

- No evident bridge-like connection.

RR Lyrae stars in the Magellanic Bridge



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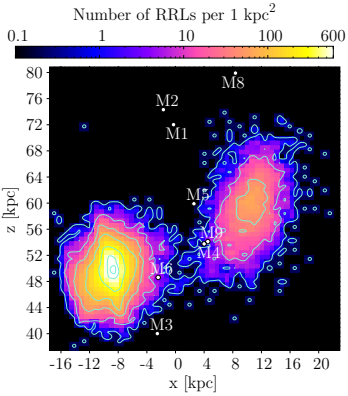
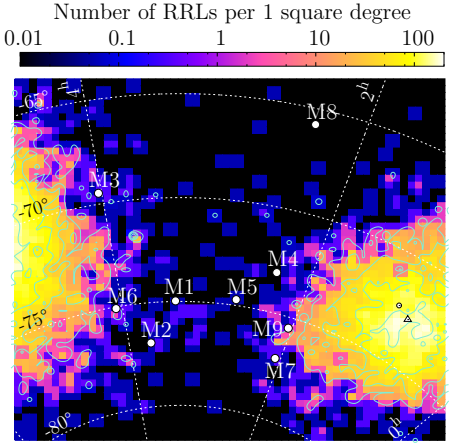


AJD et al. (2017)

- No evident bridge-like connection.
- Rather two halos overlapping (consistent with *Wagner-Kaiser and Sarajedini 2017*).

A perfect motivation



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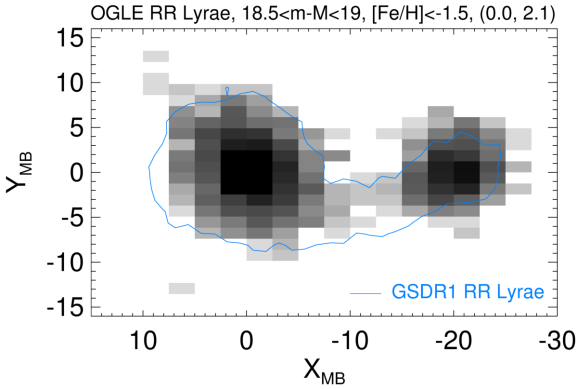
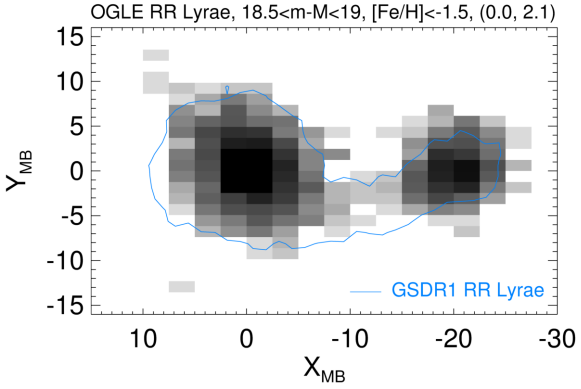


Belokurov et al. (2017)

After drawing a lot of maps...

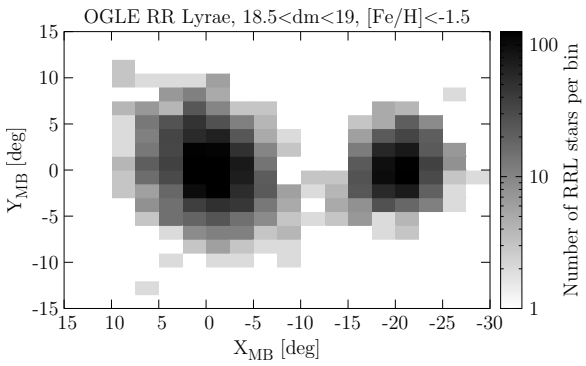
The same:

- ⋆ method
- ⋆ cuts
- ⋆ coordinate system
- ⋆ projection
- ⋆ bin size
- ⋆ bin "phase"
- ⋆ colour scale
- ⋆ range

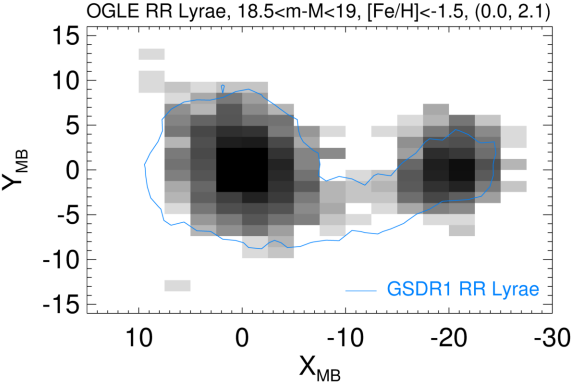


Belokurov et al. 2017

"The plotting effect"

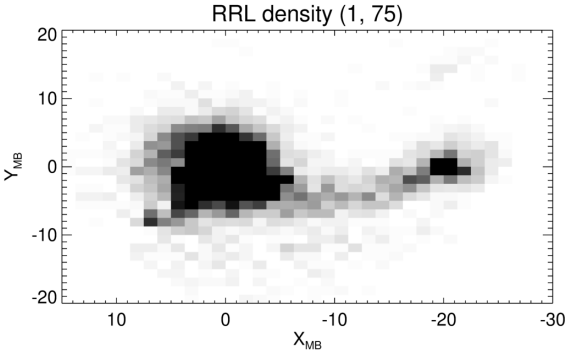


AJD et al. (2019b)



Belokurov et al. (2017)

What about their DR1 RRL candidates bridge?



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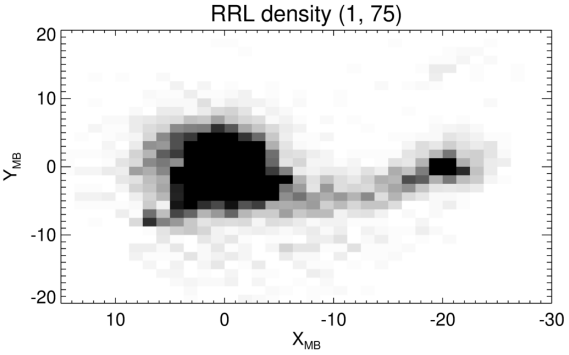


Belokurov et al. (2017)

$$\mathrm{Amp} > 0.22G - 4.87 \quad i$$

$$\left.\begin{array}{ll} \log_{10}(\mathrm{AEN}) < 0.2, & \text{weak} \\ \log_{10}(\mathrm{AEN}) < -0.2, & \text{strict} \end{array}\right\} \quad ii$$

$$18.7 < G < 20.0 \quad iii$$

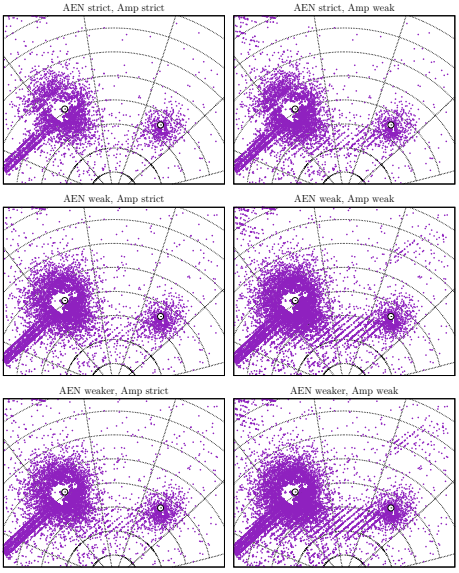
$$N_{\mathrm{obs}} > 70 \quad iv$$

$$E(B-V) < 0.25 \quad v$$

$$\left.\begin{array}{ll} -0.75 < \mathrm{Amp} < -0.3, & \text{weak} \\ -0.65 < \mathrm{Amp} < -0.3, & \text{strict} \end{array}\right\} \quad vi$$

$$b < -15^{\circ} \quad vii.$$

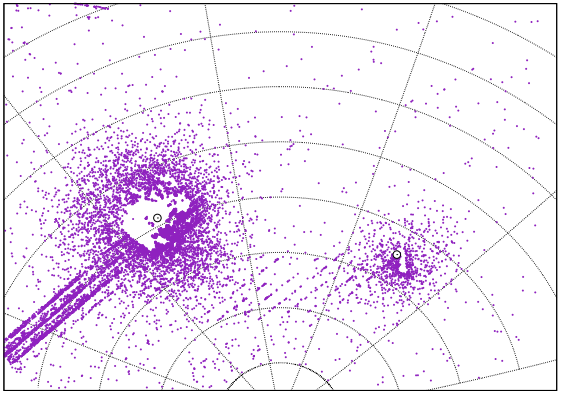
Gaia scanning pattern in the Bridge



AJD et al. (2019b)

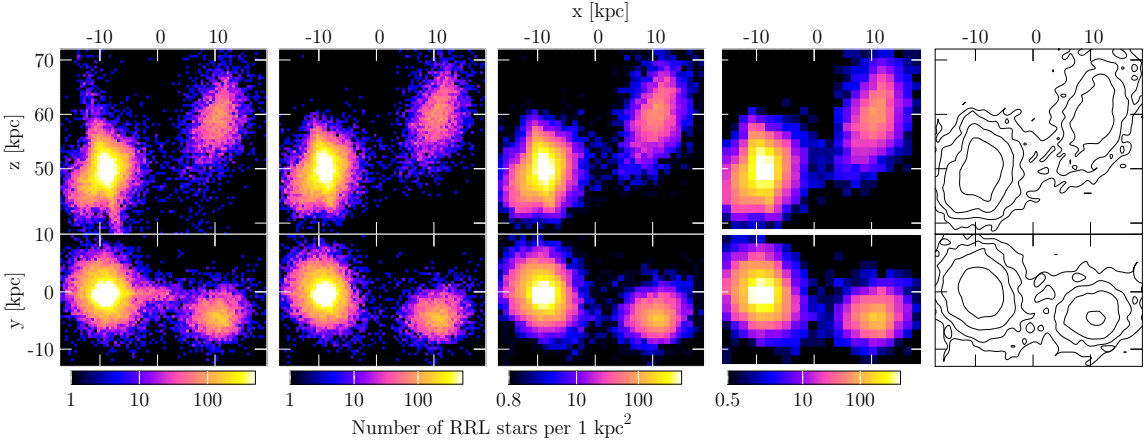
- Cuts in strict version: no bridge?
- Any cut in weak version: stripes.
- *Belokurov et al. (2017)*: stripes reflect Gaia scanning pattern and are cross-match failures in DR1.

Gaia scanning pattern in the Bridge



- ⋆ Cuts: AEN weaker, Amp strict.
- ⋆ Purity levels:
  - entire sample: 42%,
  - central Bridge part: 15%.
- ⋆ Contamination: 85% vs. $30 - 40\%$ reported by Belokurov et al. (2017).

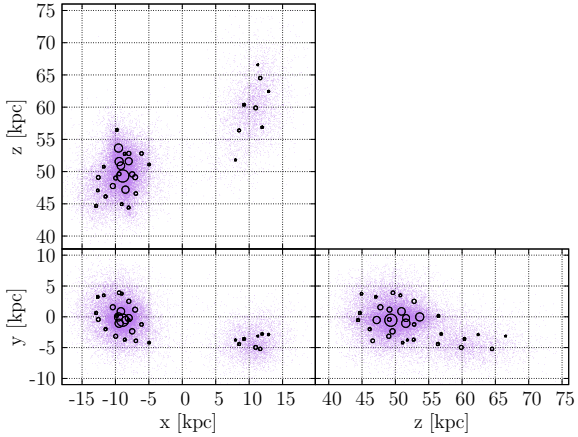
OGLE RR Lyrae stars in the Magellanic Bridge in 3d



AJD et al. (2019b)

- No evident connection. The contours connect on a very low level (below 1 star/sq. deg. and 1 star/kpc^2). → Rather two halos overlapping.

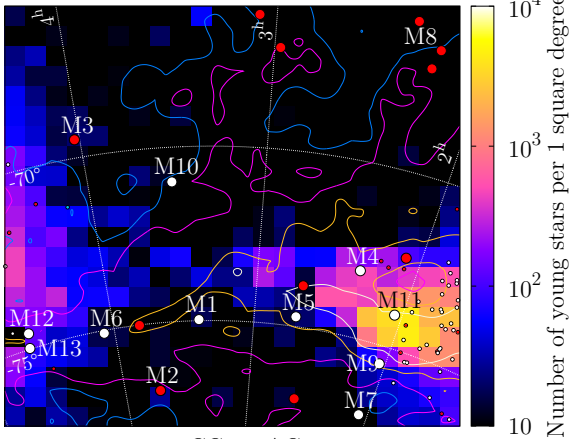
Modeling RR Lyrae distribution with Gaussians



AJD et al. (2019b)

- No Gaussian centered in the Bridge → no additional population.

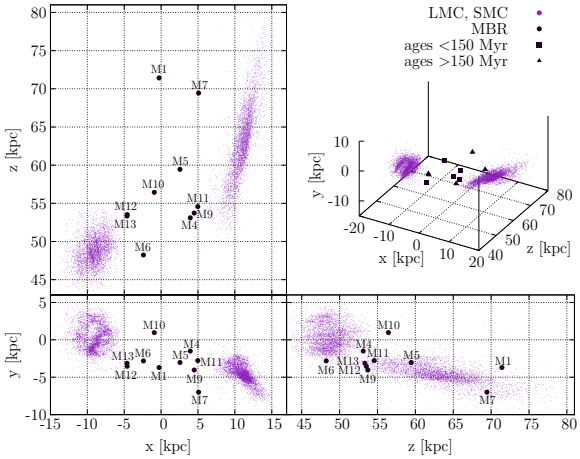
Cepheids in the Magellanic Bridge



AJD et al. (2019a)

- CCs on-sky distribution matches very well young population *(Skowron, AJD, et al. 2014)* and HI density *(Kalberla and Haud 2015)*.

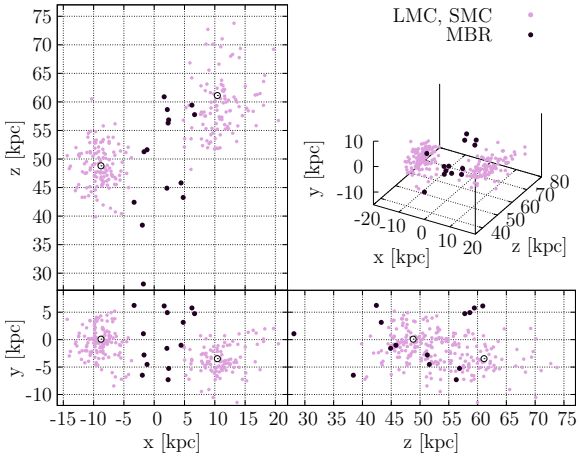
Classical Cepheids in the Magellanic Bridge in 3d



AJD et al. (2019a)

- CCs form a connection between the Clouds.
- Two of them (M1, M7) are also Counter-Bridge candidates.
- At least 5 out of 10 have ages < 300 Myr.

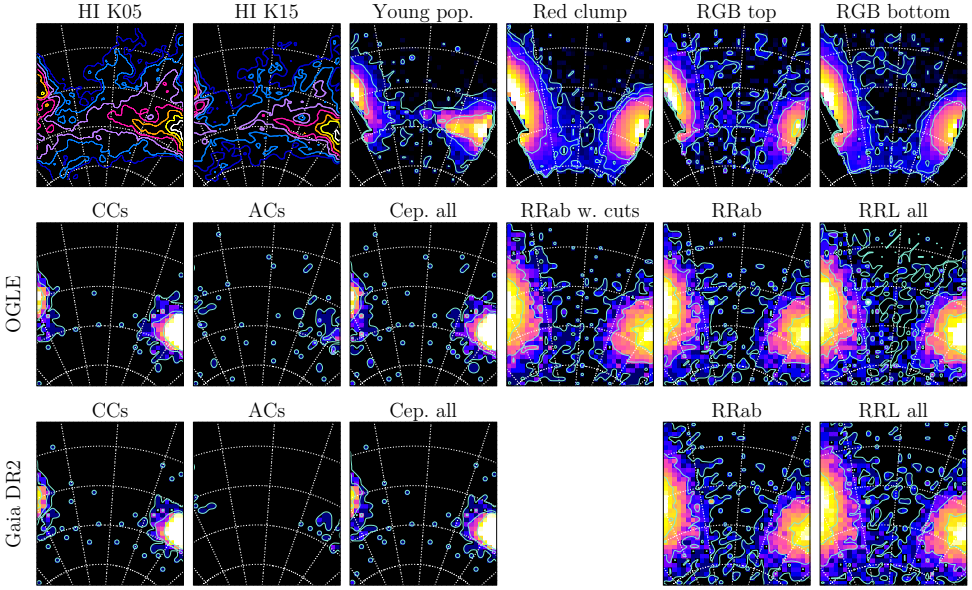
Anomalous Cepheids in the Magellanic Bridge in 3d



AJD et al. (2019a)

- Anomalous Cepheids are more spread and do not form a bridge-like connection.

A comparison of different tracers



AJD et al. (2019b)

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Thank you for attention ⌣̈