Studying eclipsing binaries (EBs) in large-scale multi-epoch surveys

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Large scale multi-epoch surveys

→ **New perspectives to study binaries/multiples**

Aims :

- Study ***specific binary systems***
- Identify ***peculiar binary systems***
- ***From*** populations of ***eclipsing binaries*** ***to*** populations of ***binary systems***

Number of EBs in some surveys

Hipparcos	:	852	(ESA SP-1200, 1997)
ASAS	:	**11'076**	(Paczynski et al. 2006)
TrES	:	773	(Devor et al. 2008)
OGLE-3 LMC	:	**26'121**	(Graczyk et al. 2011)
OGLE-3 SMC	:	6'138	(Pawlak et al. 2013)
OGLE-3 Gal. disks	:	**11'589**	(Pietrukowicz et al. 2013)
Kepler	:	2'878	(Kirk et al. 2016)
OGLE-4 LMC	:	**40204**	(Pawlak et al. 2016)
OGLE-4 SMC	:	8'401	(Pawlak et al. 2016)
OGLE-4 Bulge	:	**450'598**	(Soszynski et al. 2016)

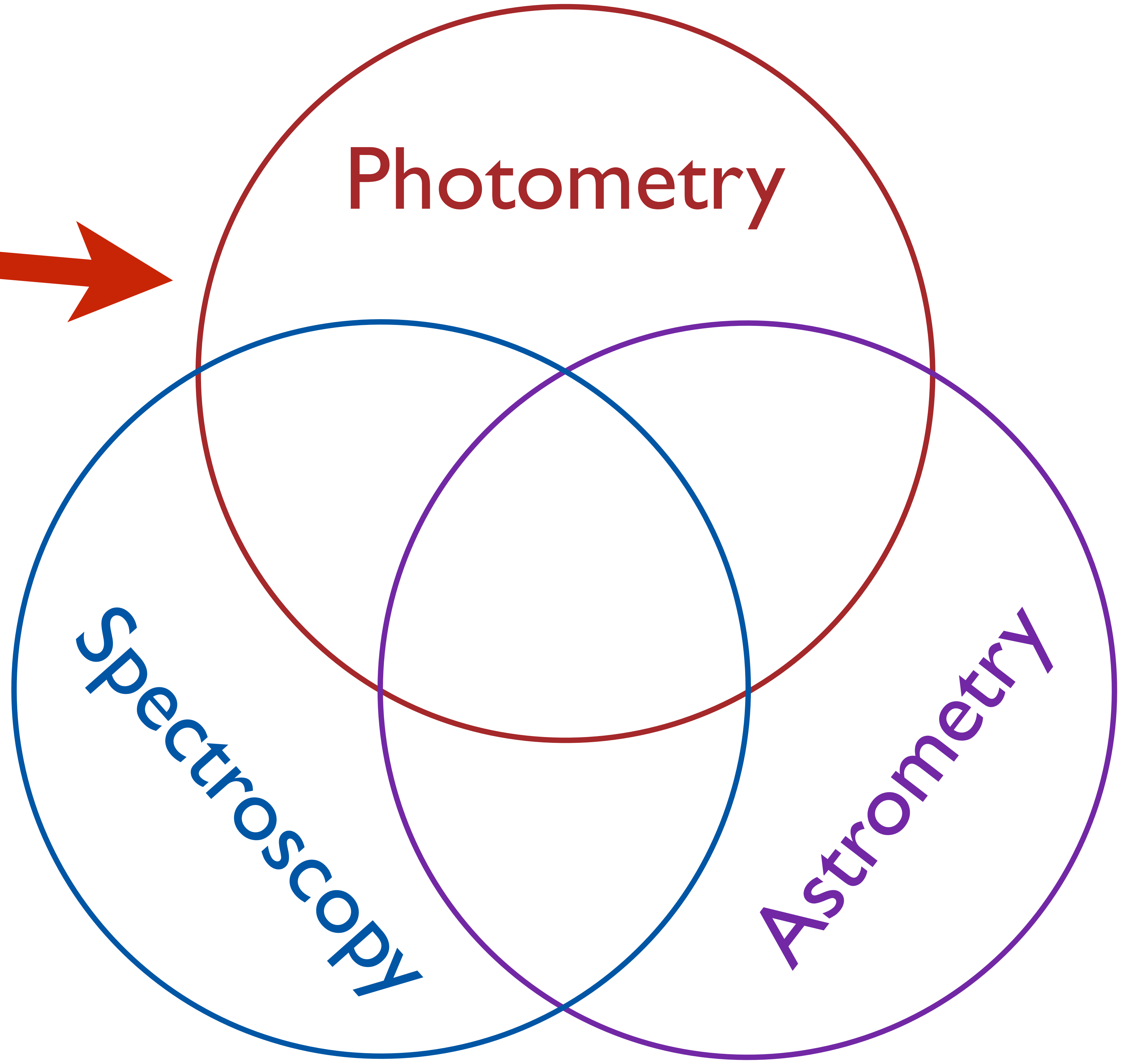
Expectations for Gaia (Eyer et al. 2013)

→ **4* (0.5-7) million EBs** (with 12*% spectroscopic binaries)

→ **8* million spectroscopic binaries** (with 59*% SB2)

→ **30* million astrometric non-single stars**

* Based on CU2 simulations of 1% of stars of the Galaxy, using Robin et al. (2012) model of Galaxy



Expectations for LSST (Prsa et al. 2011)

→ **~24 million EBs**

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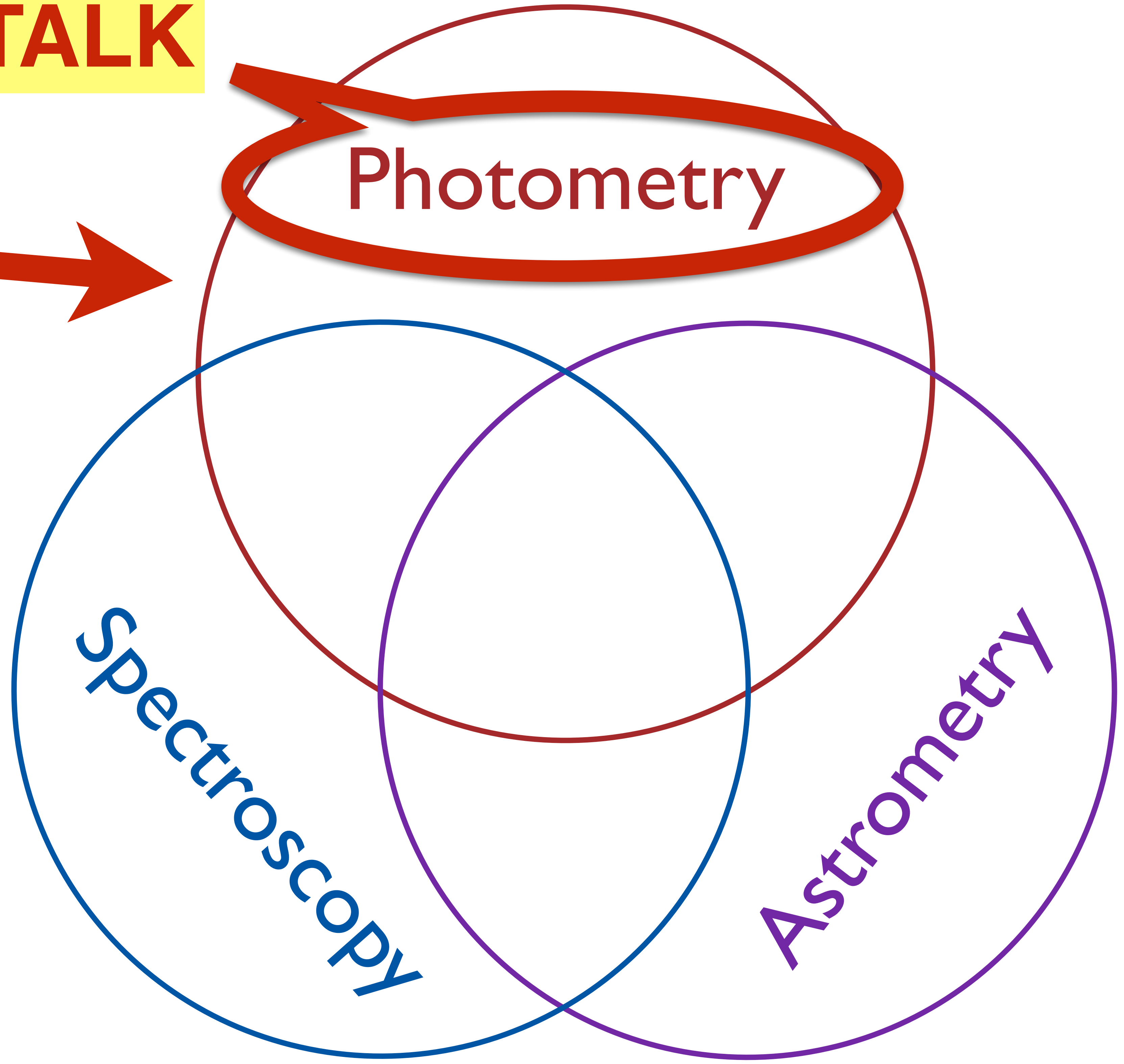
IN THIS TALK



Expectations for LSST (Prsa et al. 2011)

→ **~24 million EBs**

Challenges

1. Identification of EBs

- Variable stars
    - Periodic variables
        - Binary stars

cf. Poster 33 by B. Holl et al.

2. EB characterization

based on light curve morphology

3. EB sub-classification

in distinct classes

To be done in an automated way

Rewards

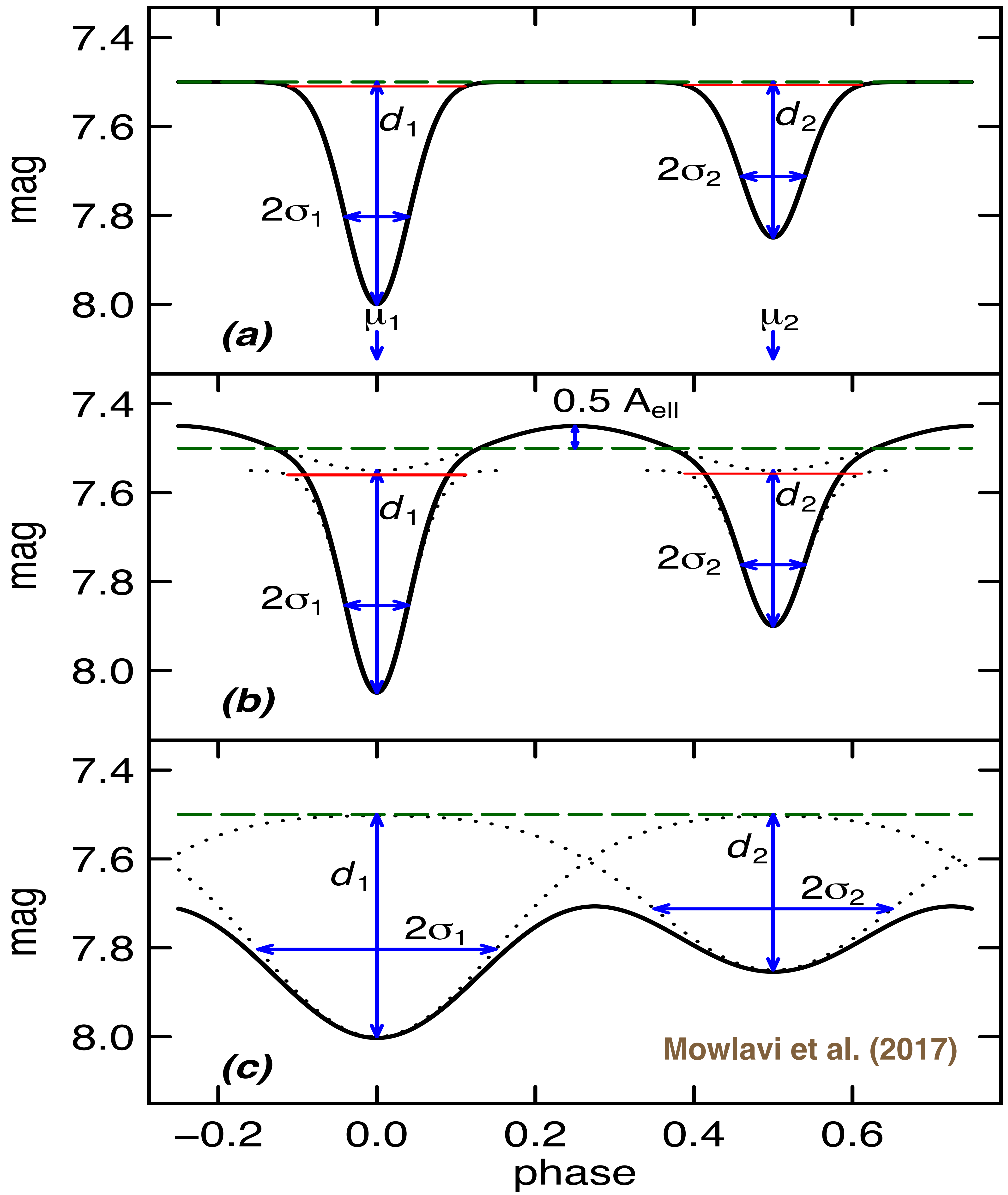
→ ***Get basic binary properties*** without full system modeling

→ ***Study populations of EBs***

→ ***Explore outliers***

Poster 33
Identification of EBs
Automatic determination of eclipsing binary periods, geometric-model and quality ranking in Gaia data
B. Holl, N. Mowlavi, I. Lecoeur-Taibi, F. Barblan, L. Rimoldini, L. Eyer, on behalf of the CU7 Consortium
(Department of Astronomy, University of Geneva, Switzerland)
OBSERVATOIRE DE GENÈVE
FONDÉ EN 1772
Observing periodic eclipsing binary signal
During 5yr Gaia observes ~0.5 - 5 million eclipsing binaries (Holl et al. 2013) with 45 to 300 epochs (70 mean).
True light curve (assumed)
phase
Observed (Example: Hipparcos sources HIP270, with 119 epochs)
Period recovery from such sparsely sampled data
An ensemble of period search methods is used to identify candidate periods
to cover the wide variety of geometric light curve shapes.
From each periodogram we extract several highest peaks and frequently occurring fractions of them
Identify candidate periods
Period search with various methods
HIP 270 Example:
String Length
Phase Dispersion Minimisation

'2-Gaussian' models



Components

- Gaussian → eclipses
- Sine half period → ellipsoidal variability
- Sine full period → reflection
- Flat bottom → total eclipses
- beaming, …

Model selection

Bayesian Information Criterion

Binary properties

→ eclipse separation
→ eclipse width
→ eclipse depth
→ Ellipsoidal variability amplitude

Example model fits to OGLE-III

Examples of classification techniques

- EA, EB, EW

  GCVS (http://www.sai.msu.su/gcvs/gcvs)

- Detached, Semi-detached, Contact

  Fourier Series parameters (Pojmanski 2002)

- One-parameter LC morphology-based

  Locally Linear Embedding (LLE; e.g. Matijevic et al. 2012)

- t-SNE + DBSCAN

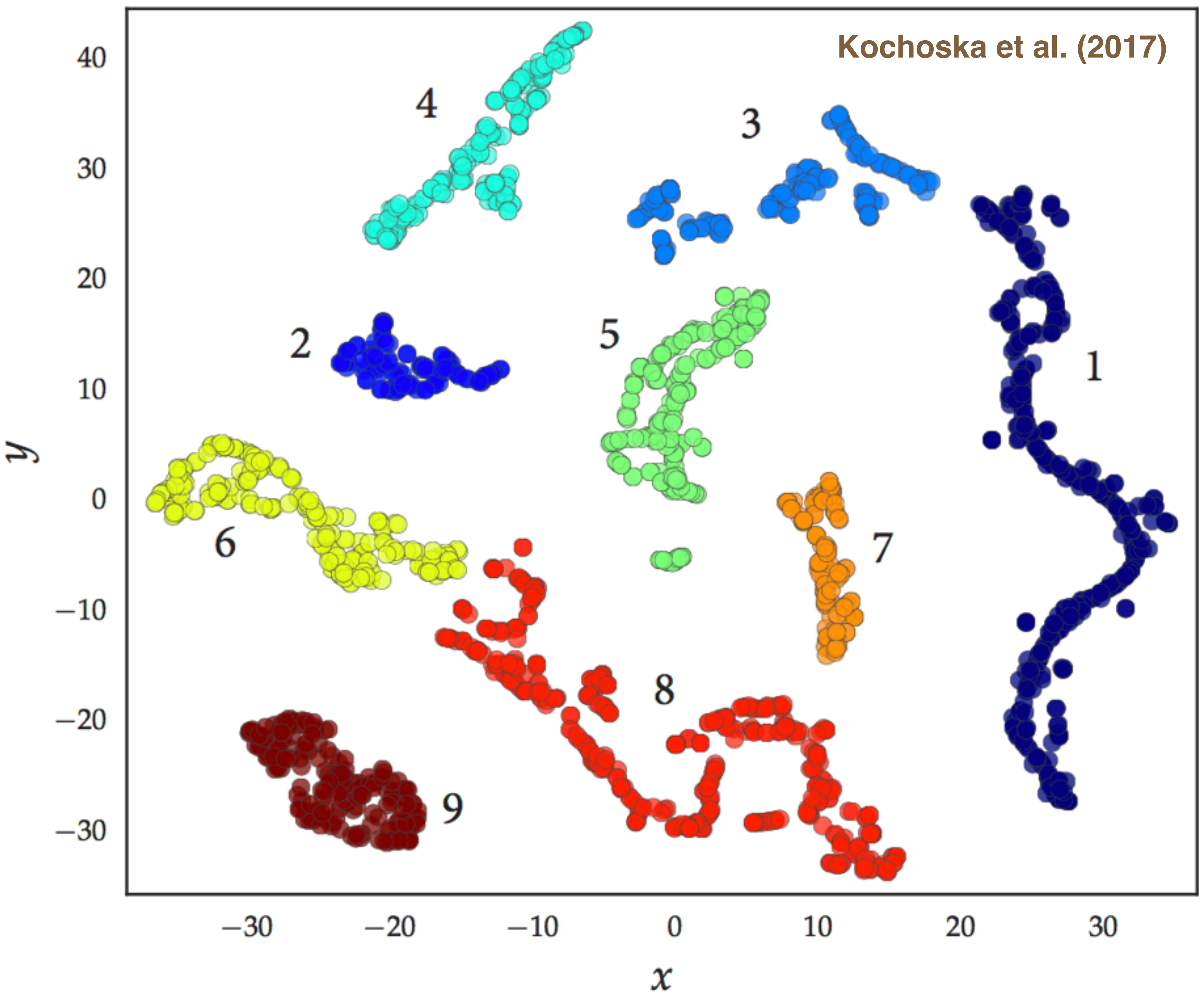
  t-Distributed Stochastic Neighbor Embedding + Density-based spatial clustering (Kochoska et al. 2017)

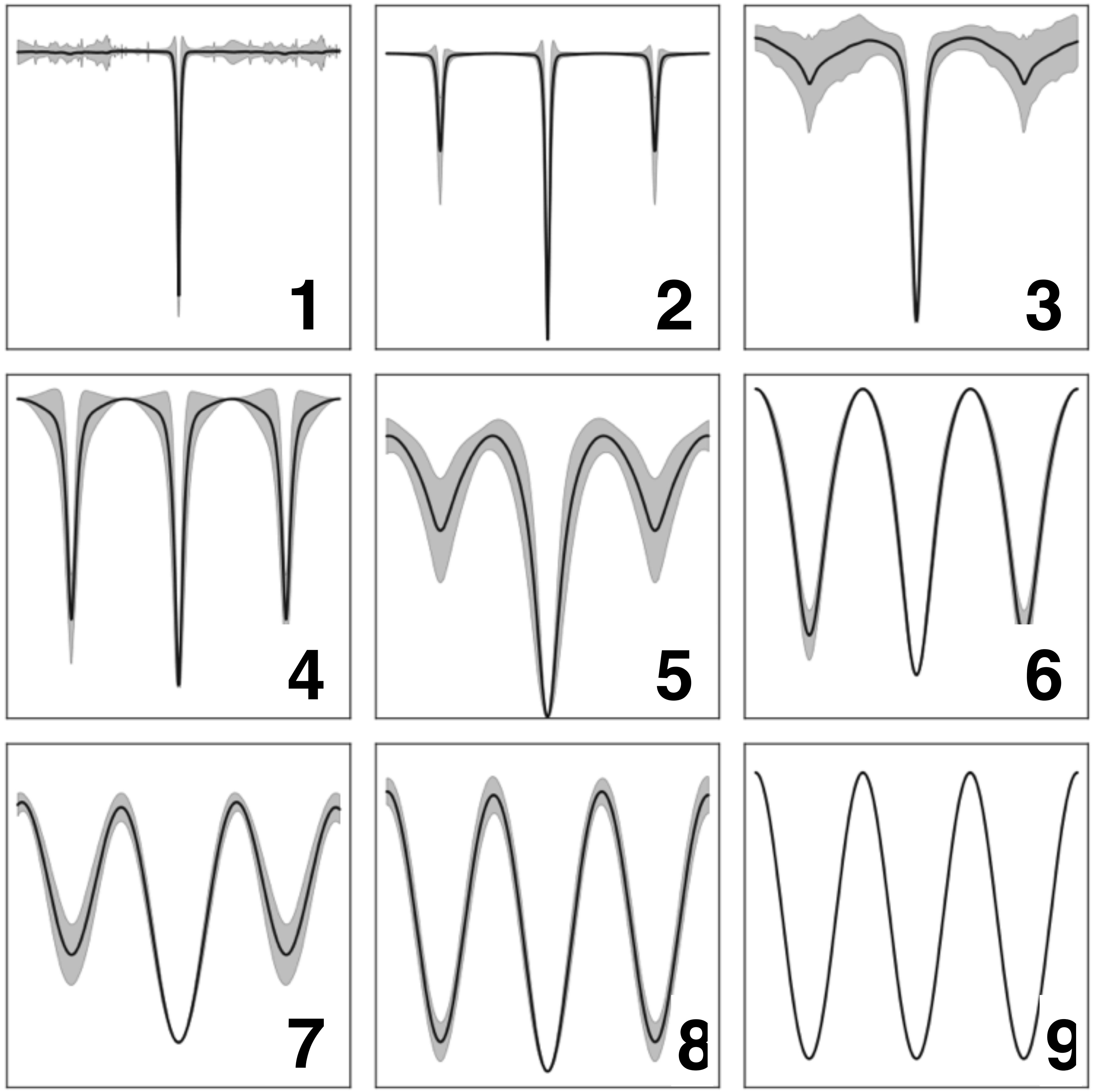
- Machine learning techniques…

  (e.g. Süveges et al 2017)

Ex: Classification based on per-point **similarity of phase-folded light curve models** using **t-SNE** (dimensionality reduction) **+ DBSCAN** (clustering algorithm)

Applied to Kepler data sampled with Gaia cadence (Kochoska et al. 2017)





How to detect peculiar cases?

Two quantities:

- **Reduced χ^2** : How well is the light curve modeled ?

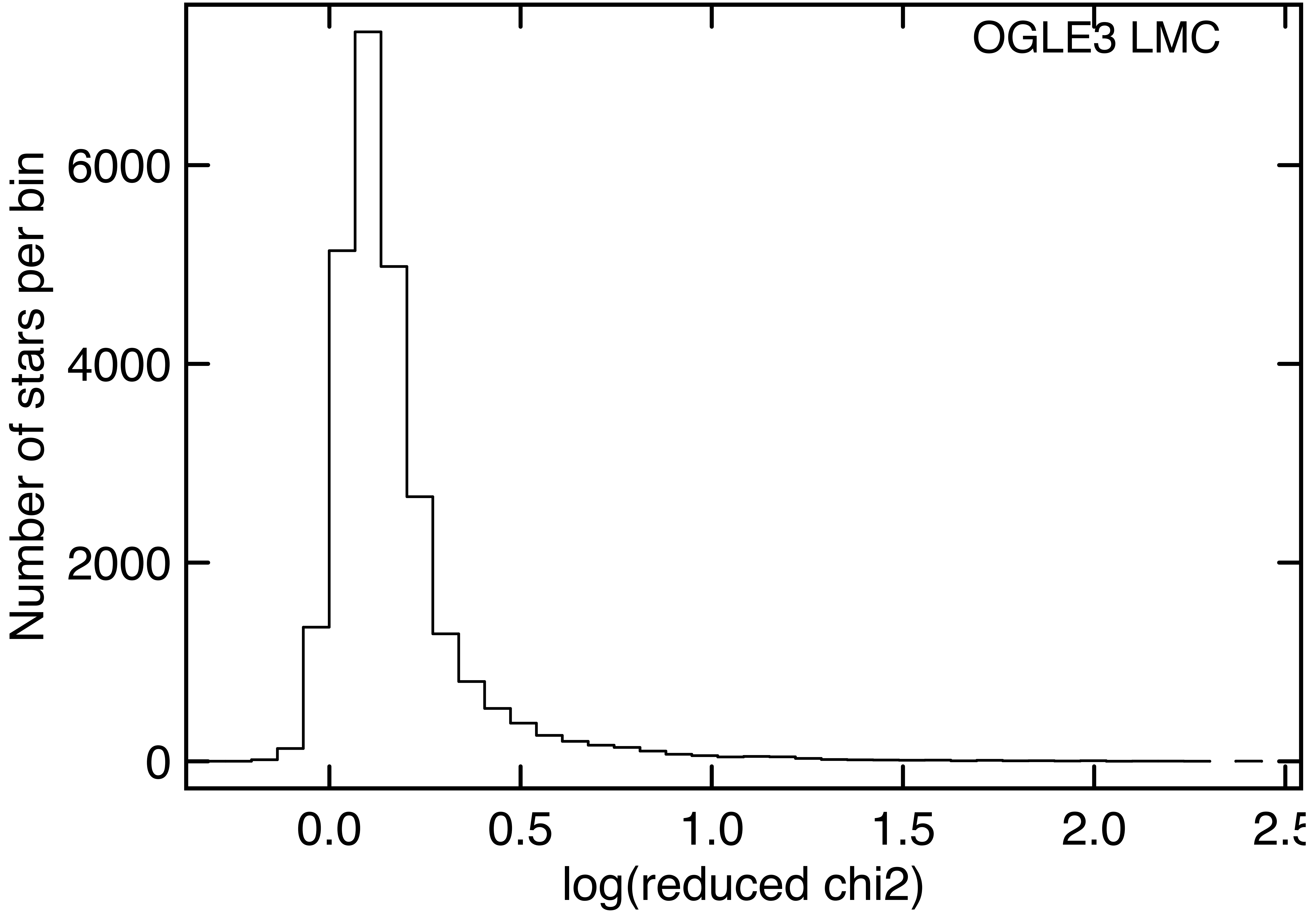
- **Abbe value** : How well is the variability pattern described ?

Application 1: Identification of peculiar cases

Reduced chi2

Test presence of intrinsic variability

$$\chi^2_{\mathrm{reduced}} = \frac{1}{(N_{\mathrm{obs}} - N_{\mathrm{param}})} \sum_{i=1}^{N_{\mathrm{obs}}} \frac{[y_i(\varphi_i) - G_i(\varphi_i)]^2}{\epsilon_i^2}$$



Application 1: Identification of peculiar cases

Abbe value

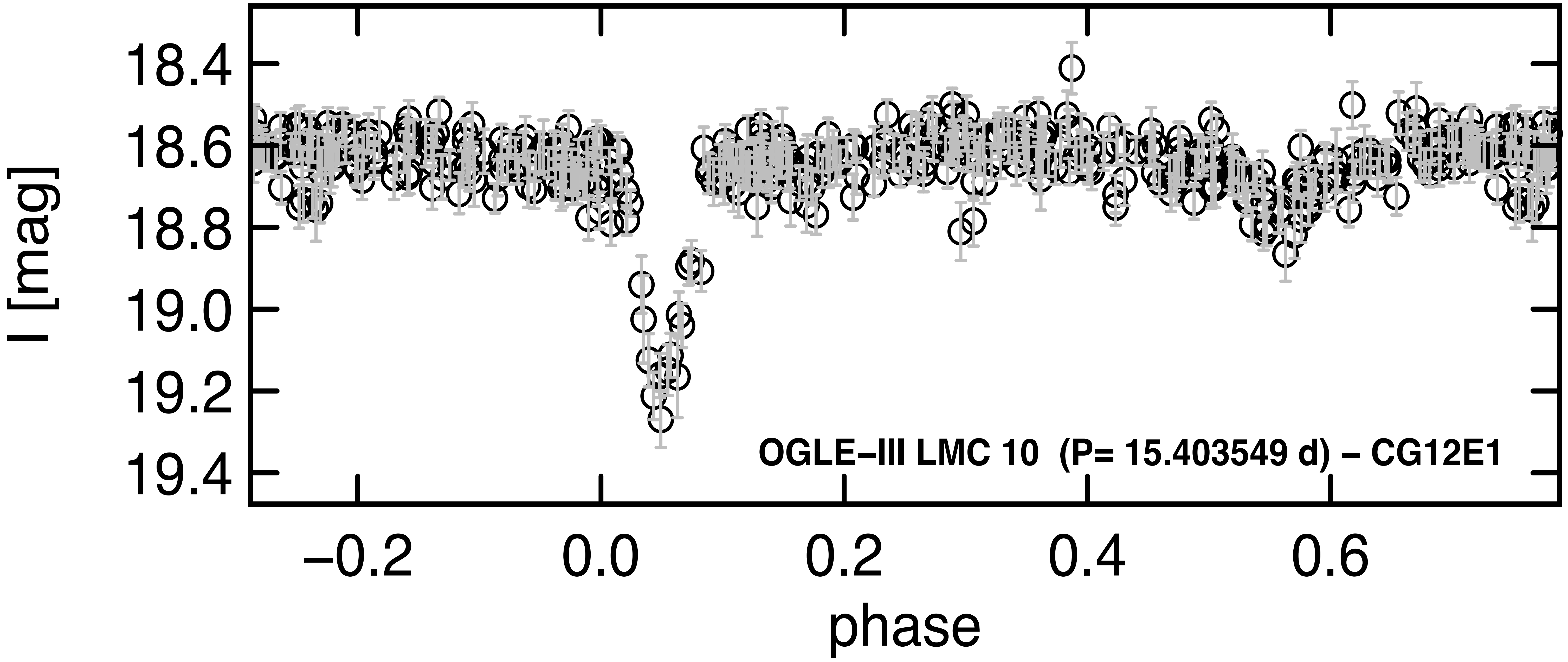
Test presence of a variability pattern

$$\mathcal{A} = \frac{n}{2(n-1)} \frac{\sum_{j=1}^{n-1}(y_{j+1}-y_j)^2}{\sum_{i=1}^{n}(y_i-\bar{y})^2}$$

No variability pattern : $\mathcal{A} \simeq 1$

Clear variability pattern: $\mathcal{A} \rightarrow 0$

Mowlavi et al. (2017)



Original LC : $\mathcal{A}$=0.27

Application 1: Identification of peculiar cases

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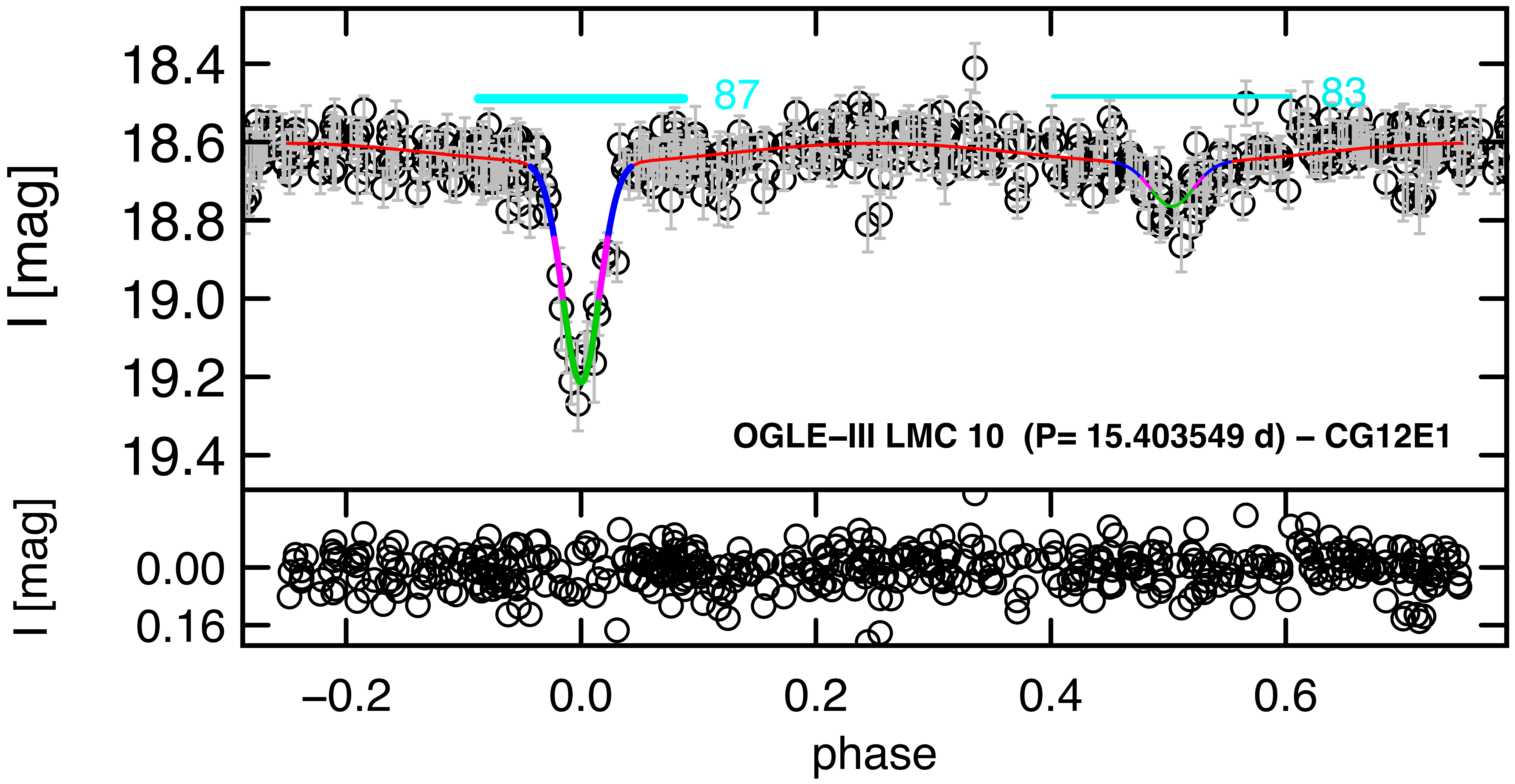

Original LC : $\mathcal{A}$=0.27
Residual LC : $\mathcal{A}$=0.93

Application 1: Identification of peculiar cases

Reduced chi2

Test presence of intrinsic variability

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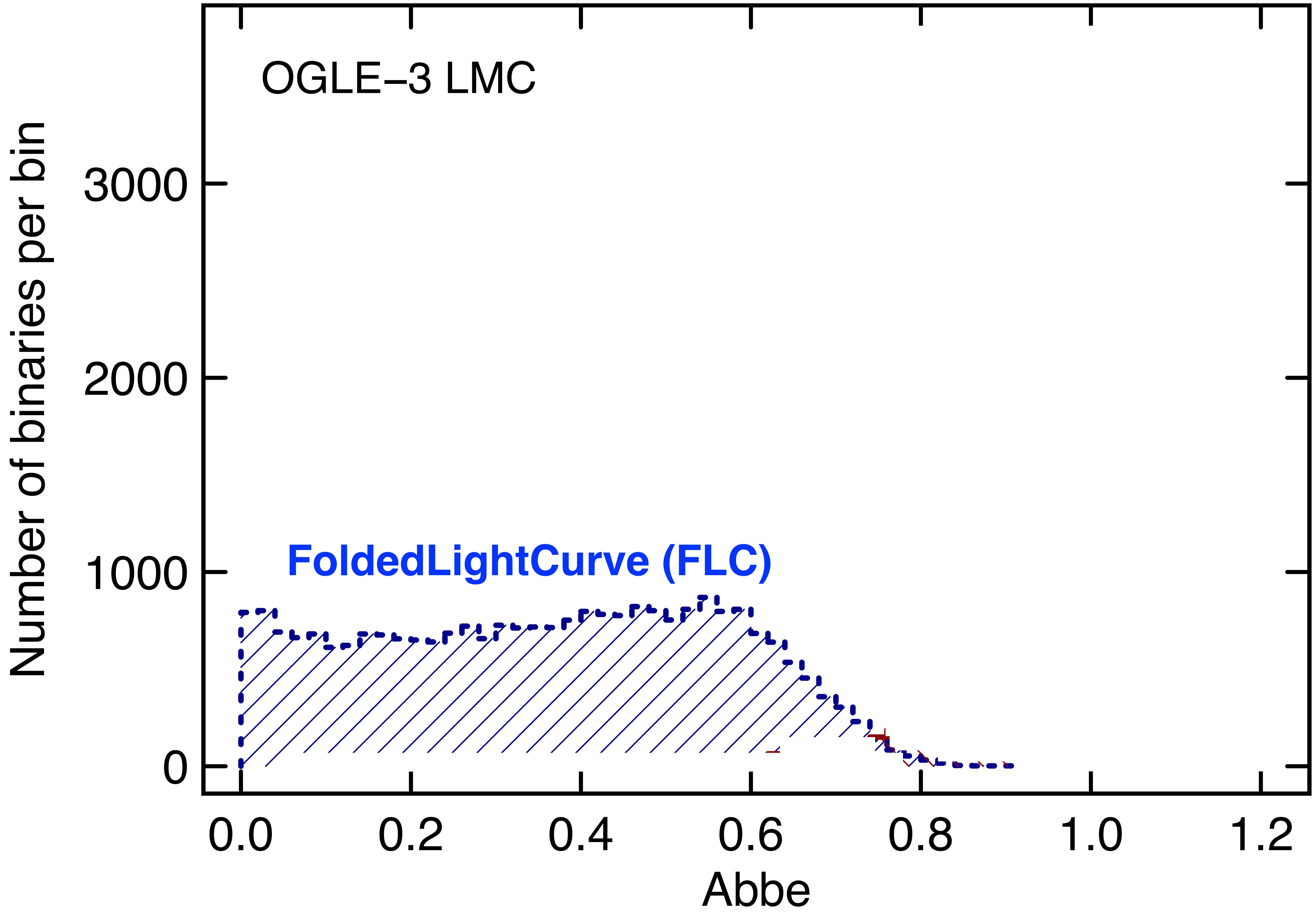

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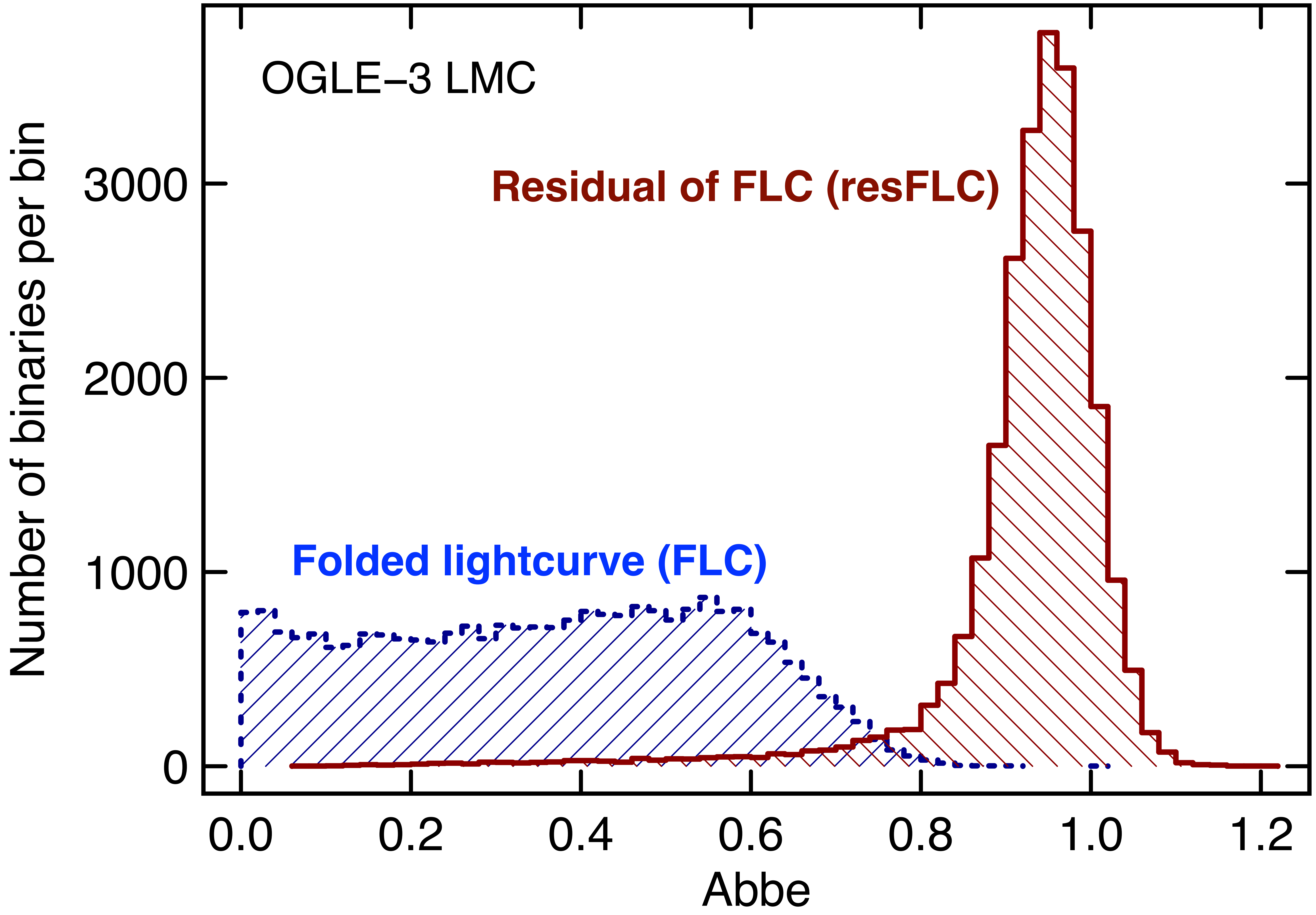
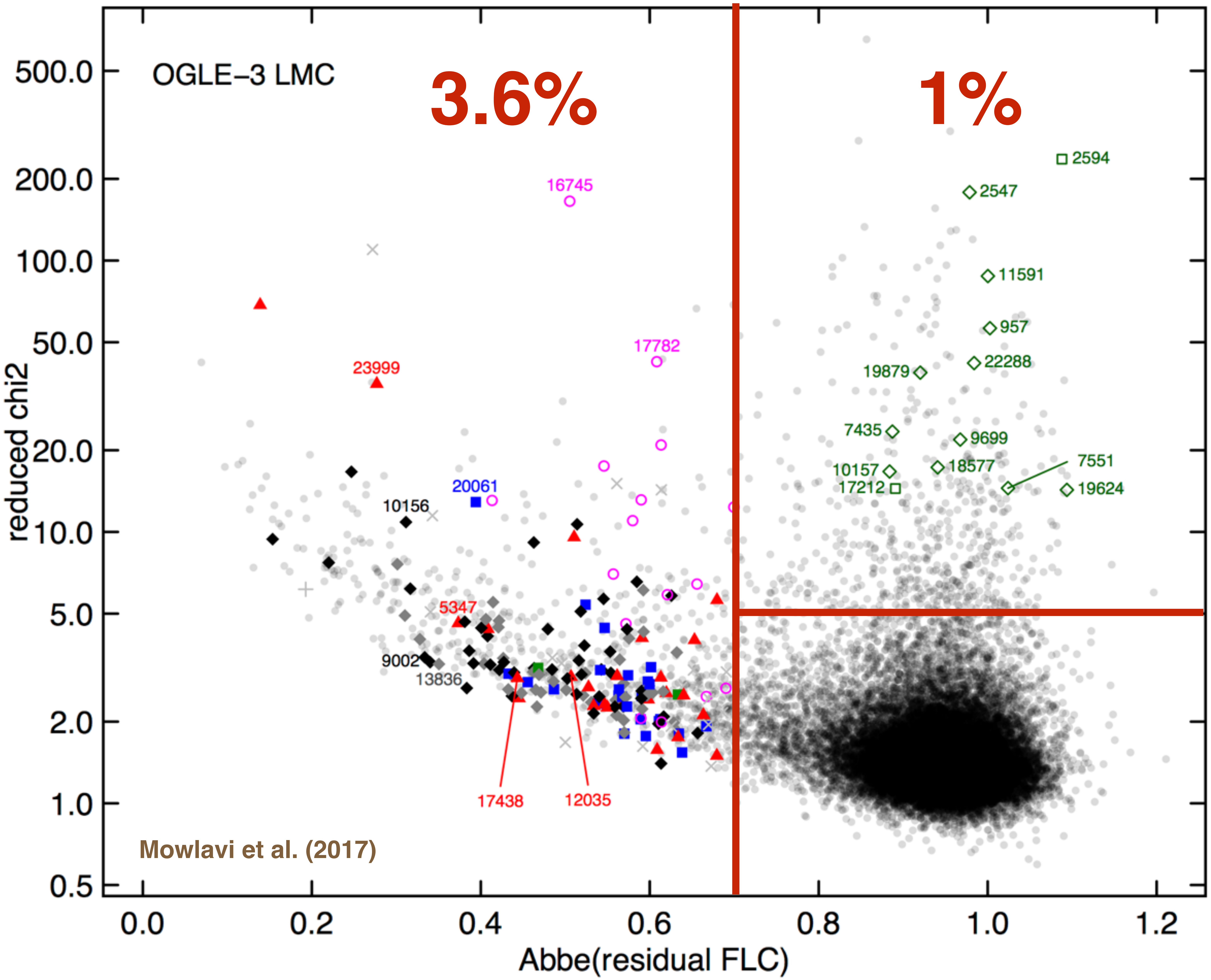
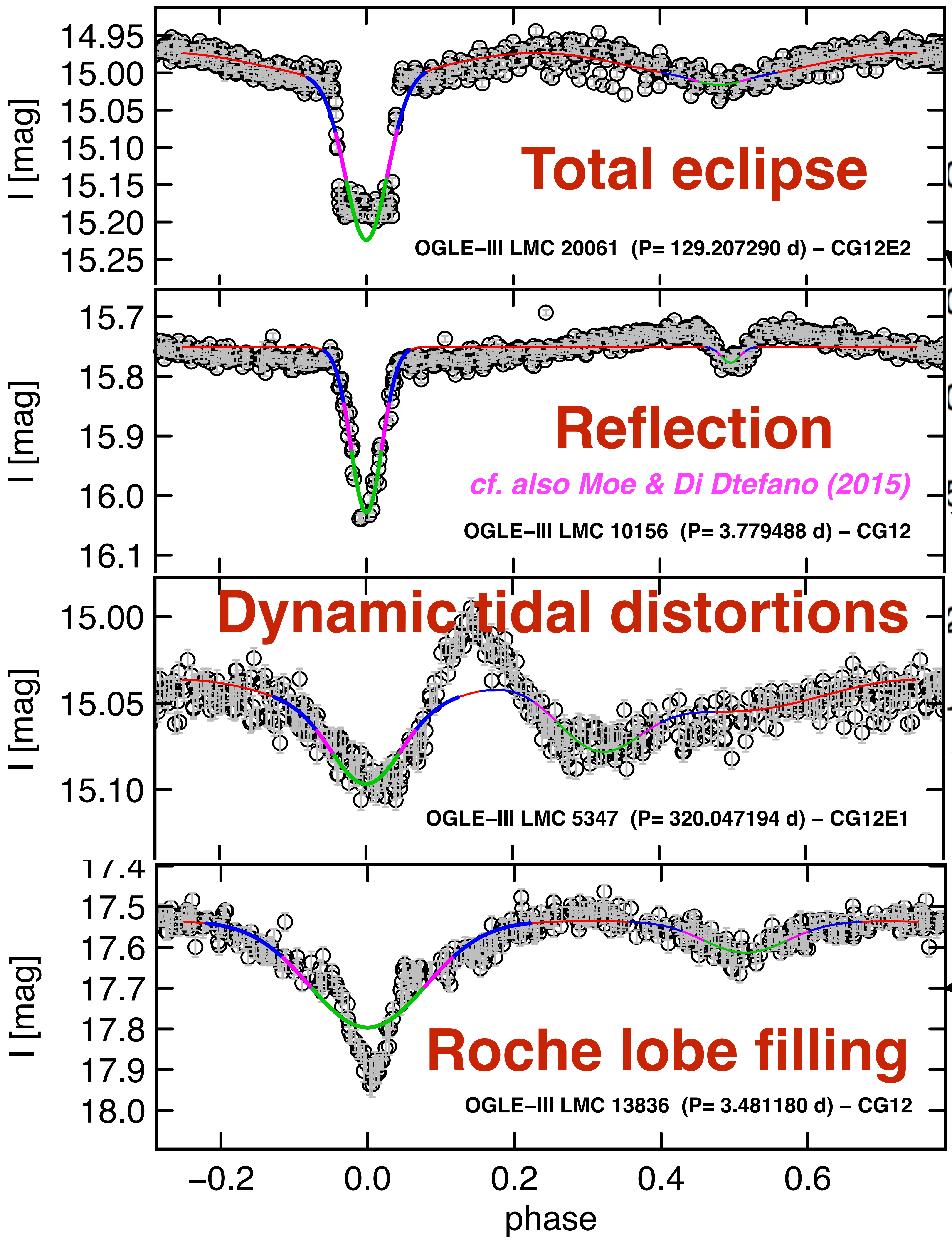
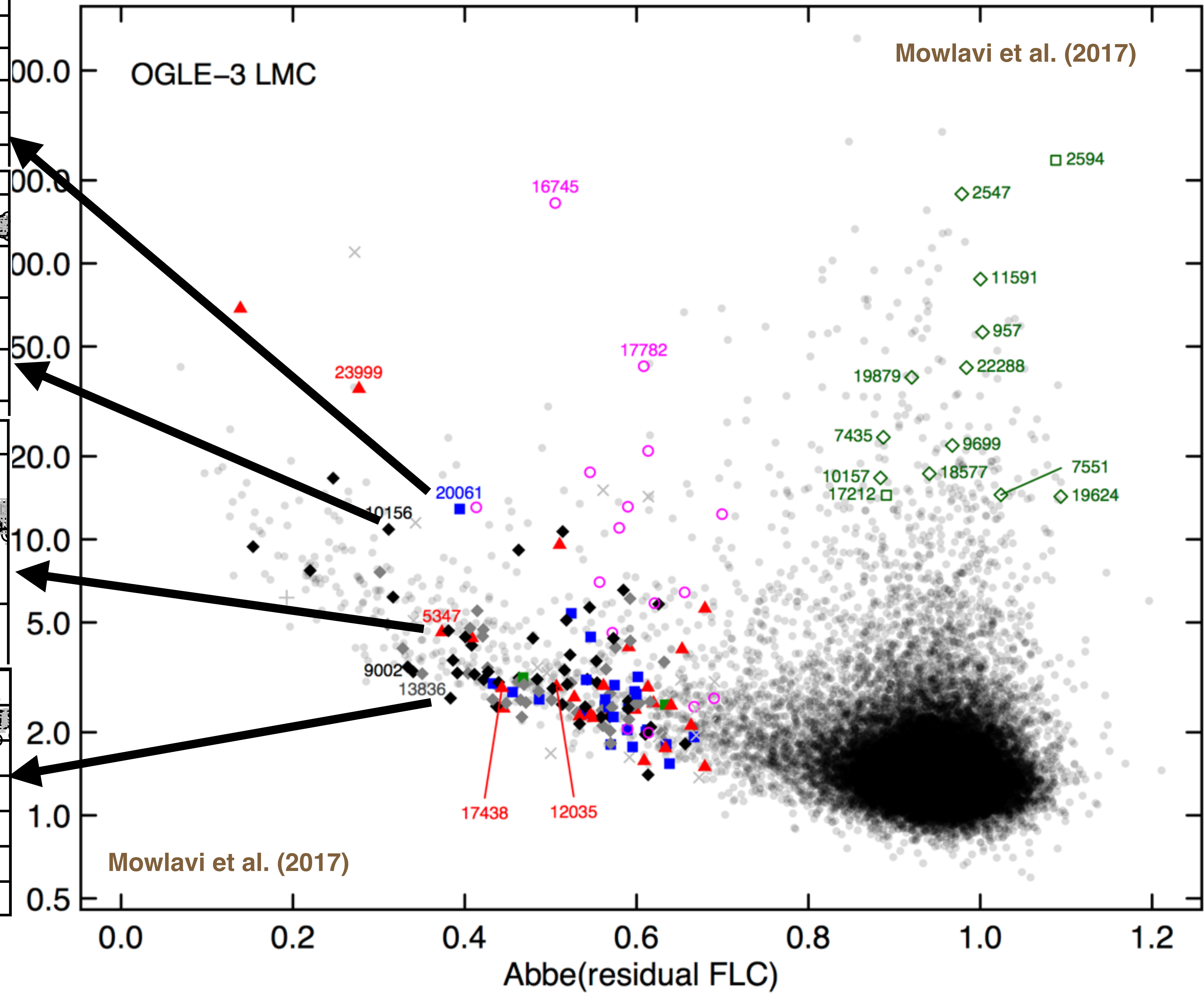



OGLE–3 LMC
3.6%
1%
reduced chi2
Abbe(residual FLC)
500.0
200.0
100.0
50.0
20.0
10.0
5.0
2.0
1.0
0.5
0.0
0.2
0.4
0.6
0.8
1.0
1.2
16745
17782
23999
20061
10156
5347
9002
13836
17438
12035
2594
2547
11591
957
22288
19879
7435
9699
10157
18577
7551
17212
19624
Mowlavi et al. (2017)

Application 1: Identification of peculiar cases





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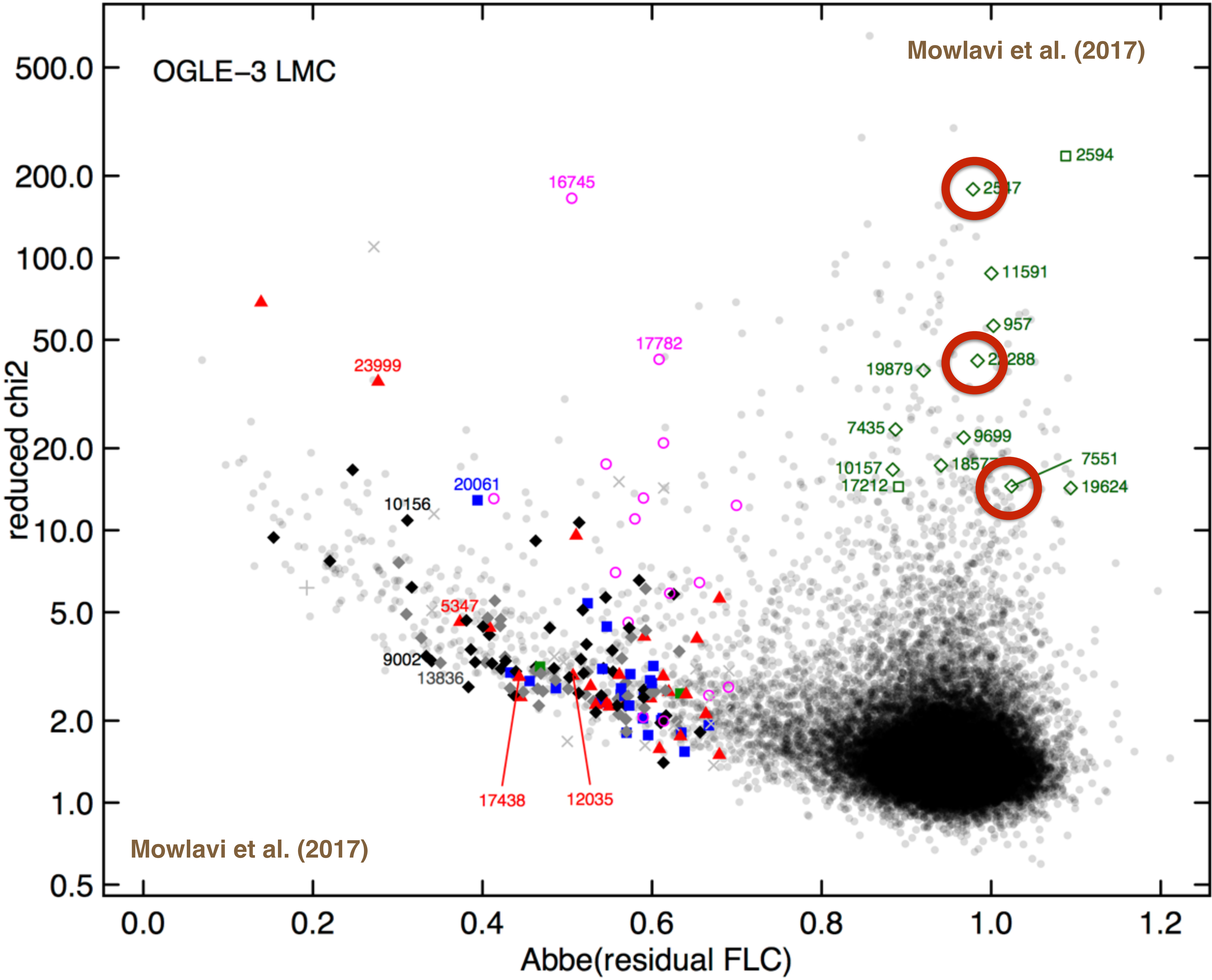
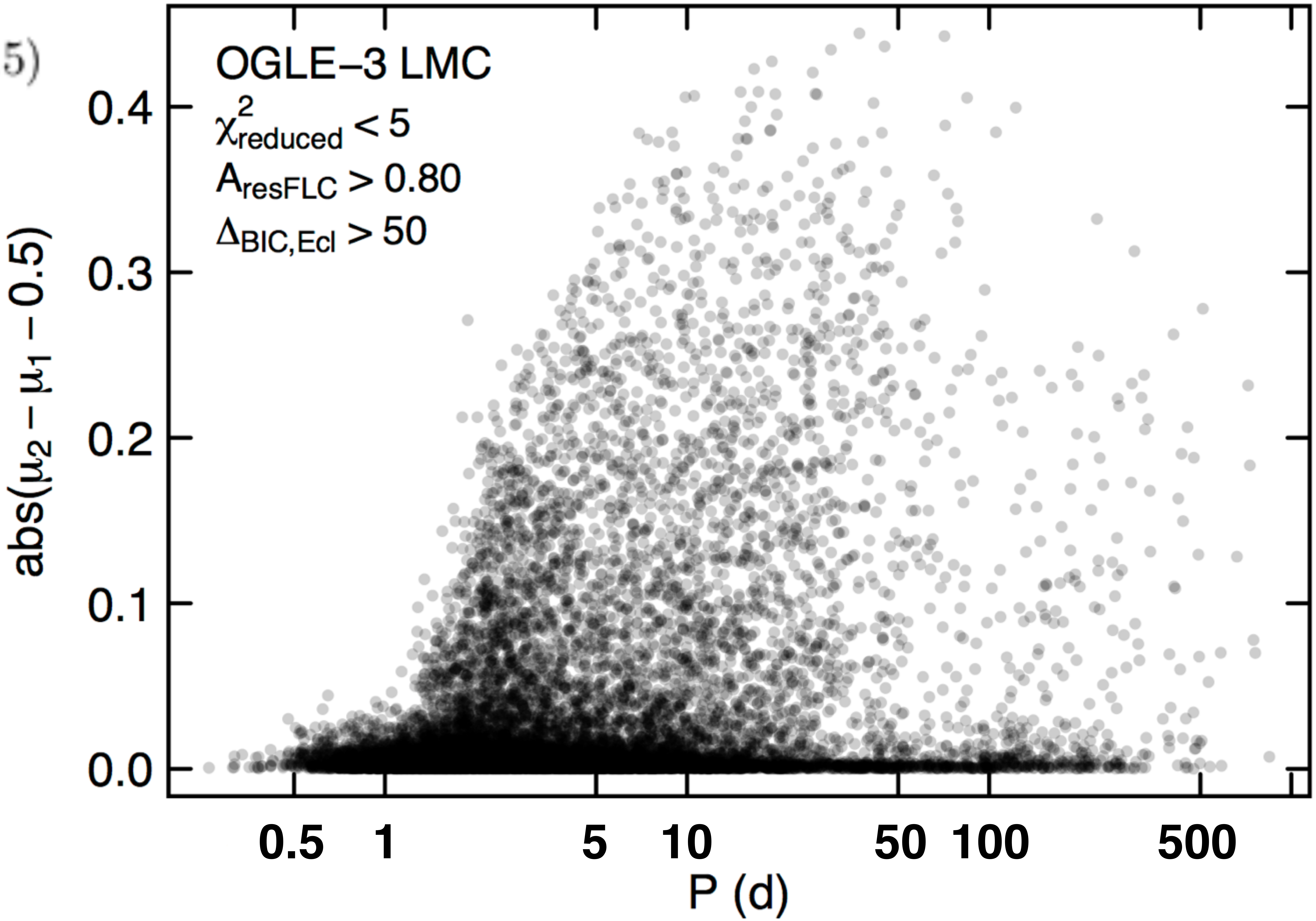


Application 1: Identification of peculiar cases

Eccentricity studies

$$e \cos \omega \simeq \frac{\pi}{2}(\mu_2 - \mu_1 - 0.5)$$

Mowlavi et al. (2017)



Application 2: Binary population study

Eccentricity studies

$$e \cos \omega \simeq \frac{\pi}{2}(\mu_2 - \mu_1 - 0.5)$$

- Select a given population
  → MS stars

- Derive eccentricities

$$e \sin \omega = \frac{w_2 - w_1}{w_2 + w_1}$$

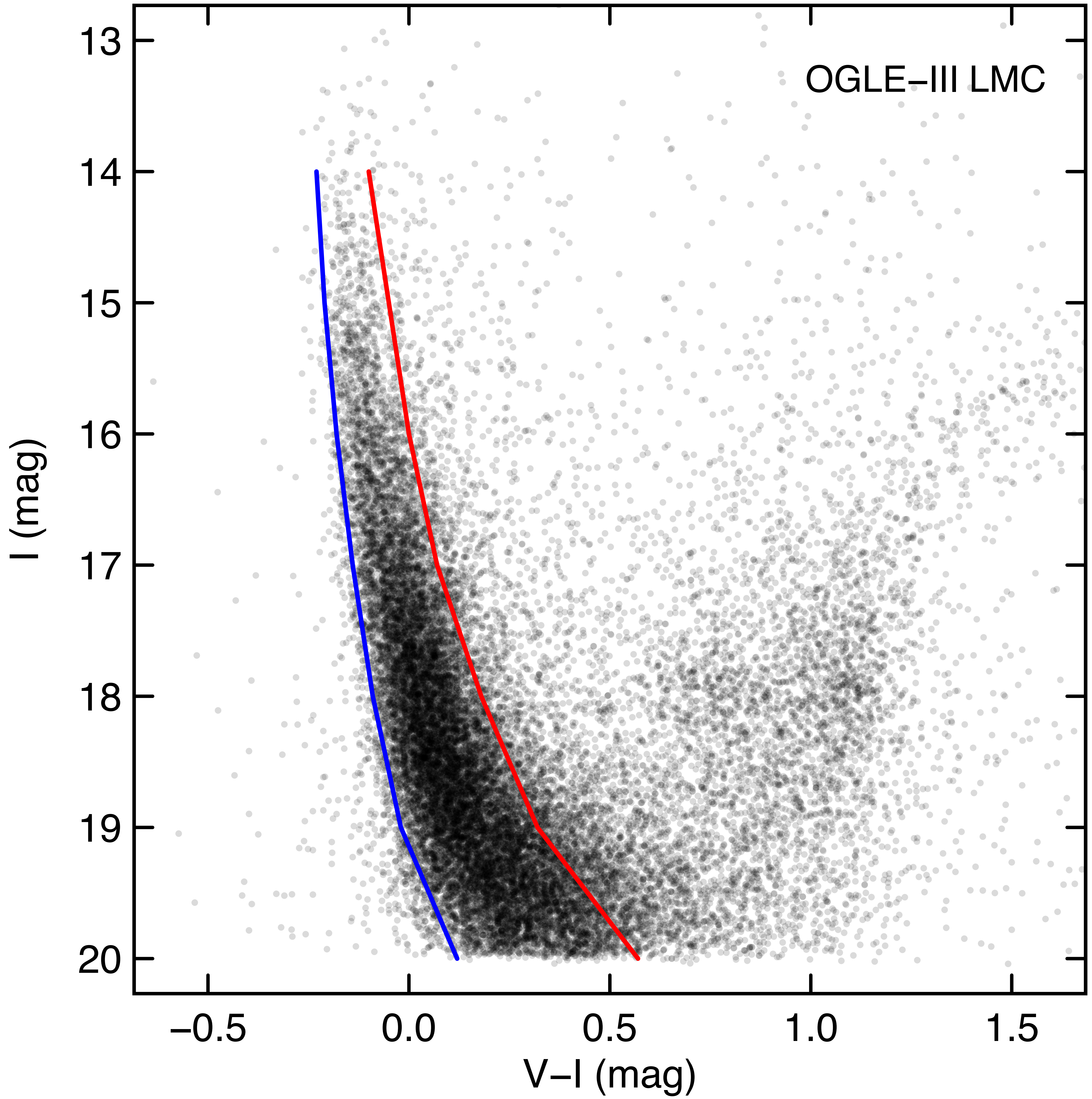
→ $$e \simeq \left[\frac{\pi^2}{4}(\mu_2 - \mu_1 - 0.5)^2 + \left(\frac{w_2 - w_1}{w_2 + w_1}\right)^2\right]^{1/2}$$

→ ***Tidal circularization studies***

Work in progress…

cf. also Poster 67 by A. Prša

Mowlavi & Mazeh (in prep.)



From populations of eclipsing binaries …

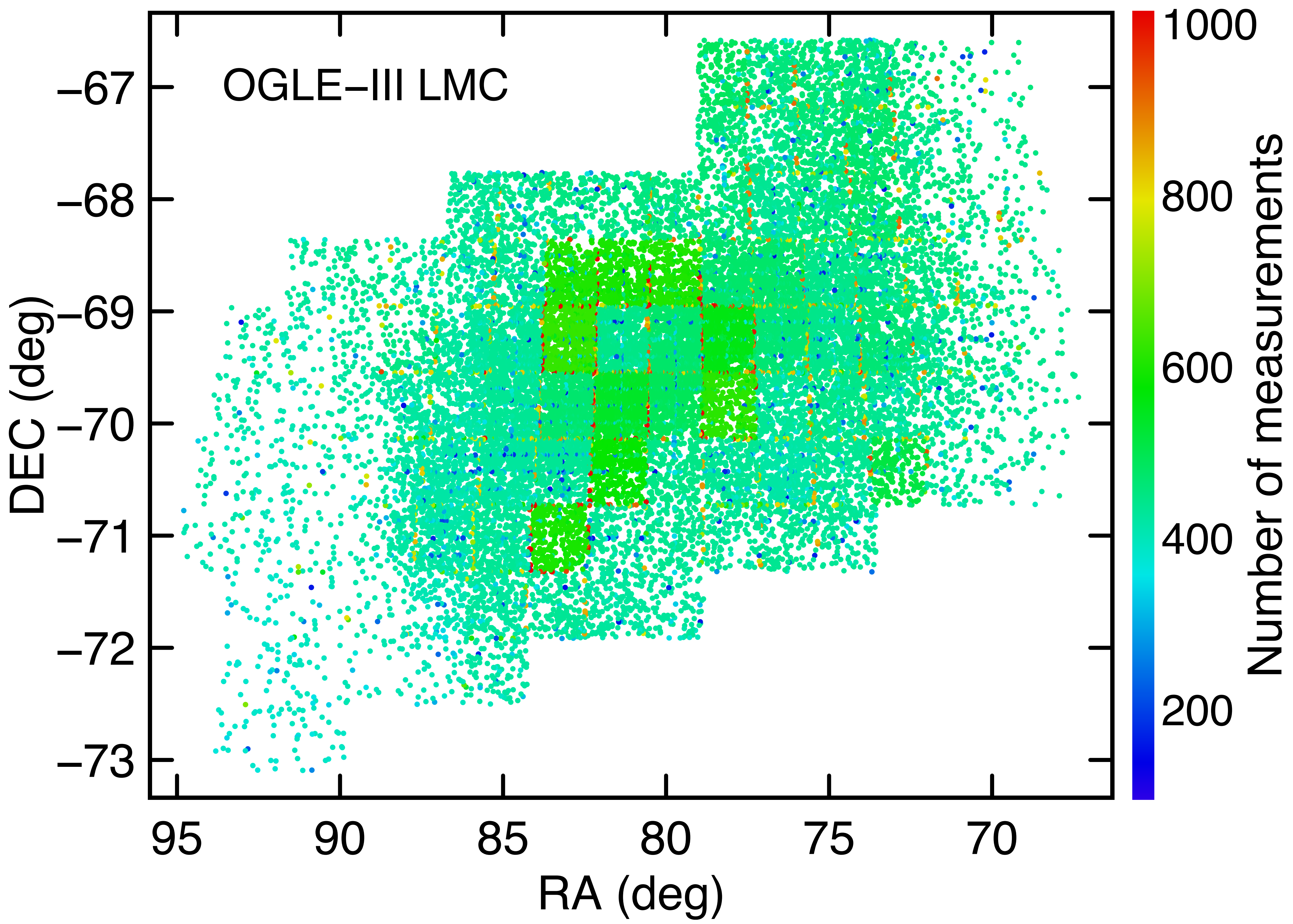
… to populations of binary systems

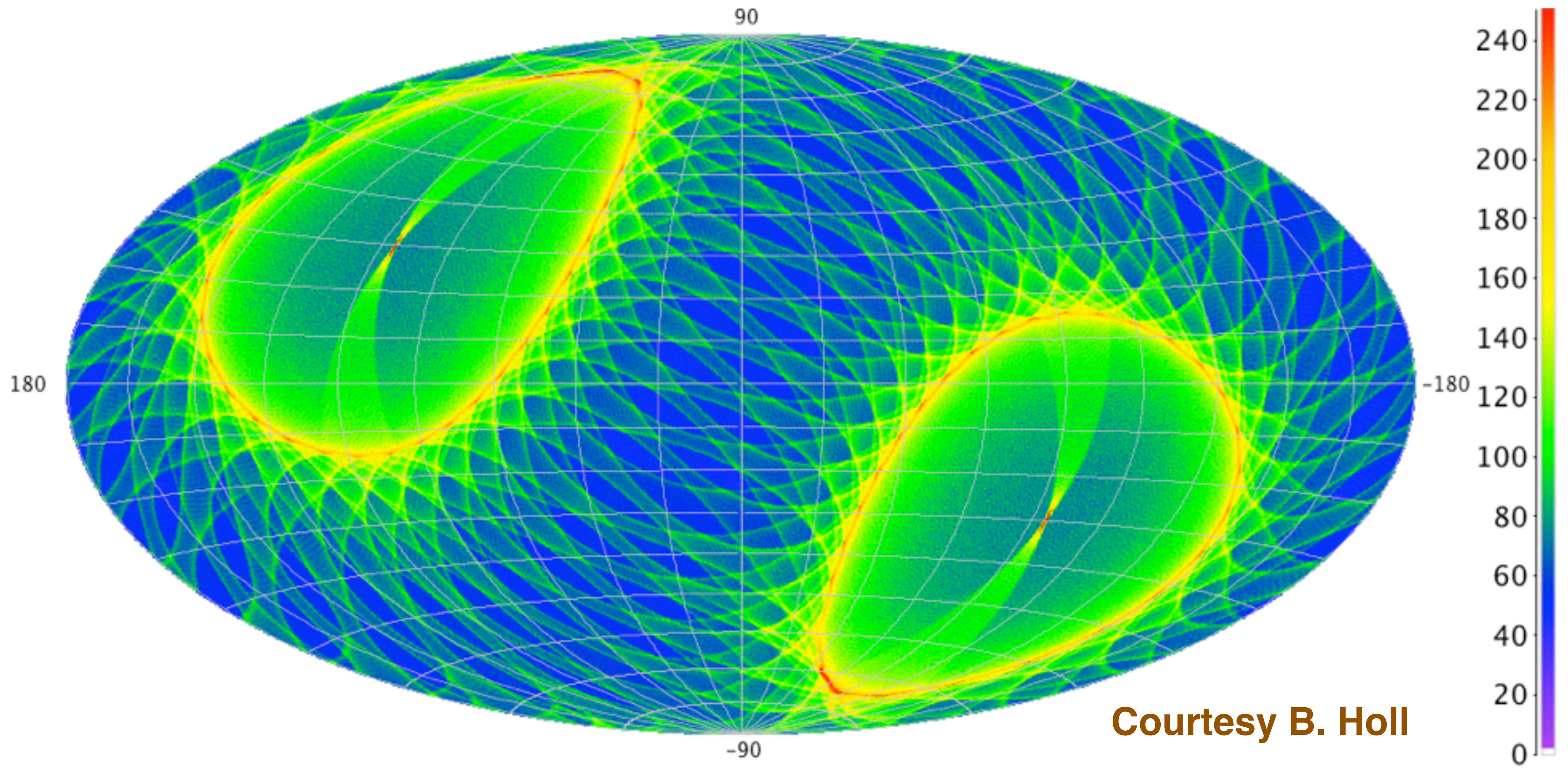
Selection effects !

For example, **~70% of Kepler EBs potentially detectable with Gaia**

(due to time sampling effects, Kochoska et al. 2017)

→ Evaluate transfer functions to convert from pop. of EBs to underlying pop. of binaries





Courtesy B. Holl

Conclusion

Large scale multi-epoch surveys

→ New perspectives to study binaries/multiples

Hipparcos:	~0.001	million EBs	*1997*
Ogle 3 :	~0.04	million EBs	*2013*
Ogle 4 :	~0.5	million EBs	*2016*

Predicted

Gaia :	~4	million EBs	*2022*	⟶ + Spectroscopy and astrometry
LSST :	~24	million EBs	*2021-2031*	