Search for transits in NGC 7243 - current status of the project

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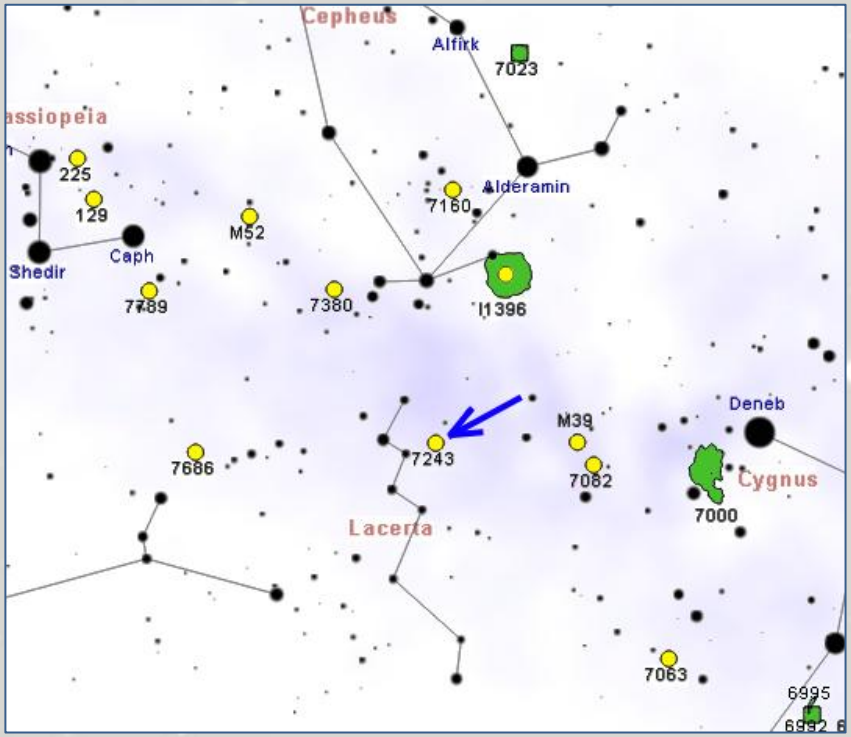
Introduction

- **Basic facts about NGC 7243:**
  - it was discovered by **W. Herschel** in **1787/1788**,
  - alternative name of the cluster is **Caldwell 16**,
  - it is located in the **Lacerta** constellation,
  - central coordinates of the cluster: **α = 22:15:08, δ = +49:53:51**.



Introduction

- **YETI target selection criteria and the open stellar cluster NGC 7243:**
  - For successful detection of a young exoplanet **is very important to choose regions on the sky** where is a high probability to observe its transits.
  - **Young open clusters** are ideal targets for photometric observations.

- **Target selection criteria:**	**NGC 7243:**
- Many young stars in one FoV.	**211**
- The age of the clusters: 1 Myr – 100 Myrs.	**76 Myrs (250 Myrs?)**
- The distance of the clusters: 50 – 1000 pc.	**698 – 750 pc**
- The angular size of the cluster: smaller than 1x1°.	**21 arcmin**
- The magnitude range of stars: V = 10 – 16 mag.	**V = 8.43 – 15.5 mag**
- Location on the sky (observable for YETI telescopes).	**Lacerta constellation**

- **Based on these criteria the open cluster NGC 7243 is an ideal YETI target.**

Introduction

- **Comparison with other selected clusters:**

Open cluster	RA [h:m:s]	Dec [° : ' : "]	Monitoring dates (start - end)	Age [Myr]	D [pc]
Trumpler 37	21:39:00	57:29:24	2009 Aug - 2011 Sep	~4	870
25 Ori	05:24:45	01:50:47	2010 Oct - 2013 Feb	7-10	323
IC 348	03:44:34	32:09:48	2012 Sep - 2014 Nov	~2	316
Collinder 69	05:35:06	09:56:00	2012 Nov - 2015 Feb	~5	400
NGC 1980	05:35:24	-05:54:54	2013 Feb - 2015 Feb	4-5	400
NGC 7243	22:15:08	49:53:54	2013 Aug - 2015 Nov	~76	750
NGC 869	02:19:00	57:07:42	2016 Oct - ongoing	12	2079
NGC 884	02:22:18	57:08:12	2016 Nov - ongoing	11	2345
IC 4665	17:46:18	05:43:00	2017 May - ongoing	43	352

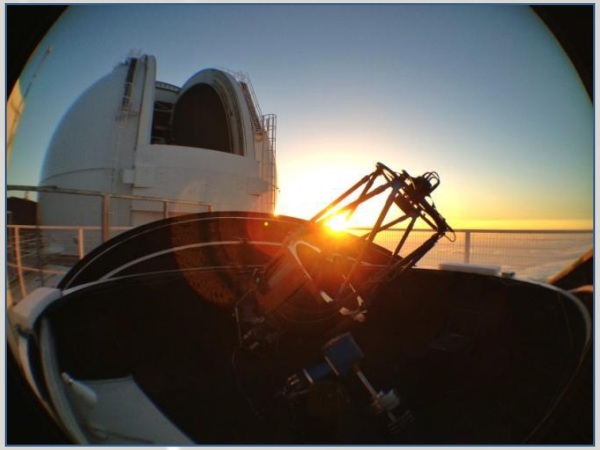
Observations and Data analysis

- Observations:

- The monitoring of NGC 7243 started in summer 2013 with two observing campaigns:

- 1st	2013.08.03 - 2013.08.14
Observatory:	Observing nights:
- SLO	8
- GSH	4
- LPO	12
- 2nd	2013.08.31 - 2013.09.12
Observatory:	Observing nights:
- SLO	6
- GSH	5
- LPO	7

- Additional data were obtained also before and after the campaigns.



Observations and Data analysis

- **Observations:**
  - **In some cases we detected only a single transit-like event or eclipse.** We observed NGC 7243 also in 2014 during 3 observing campaigns (and add. obs.):

- 3rd 2014.09.02 - 2014.09.14

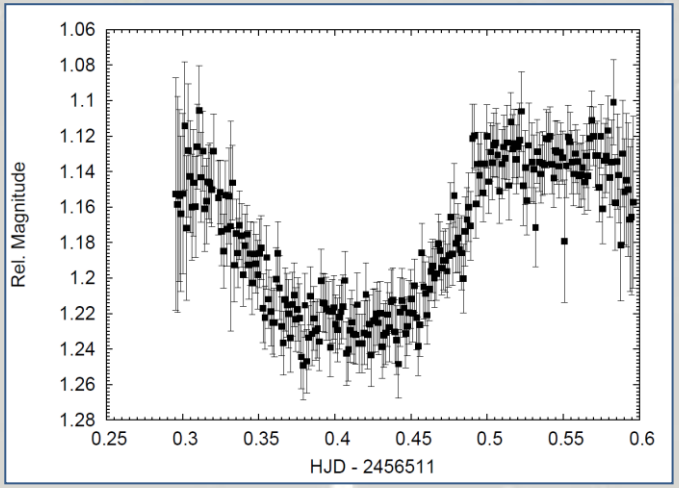
Observatory	Observing nights
- SLO	4
- GSH	2
- LOT	8

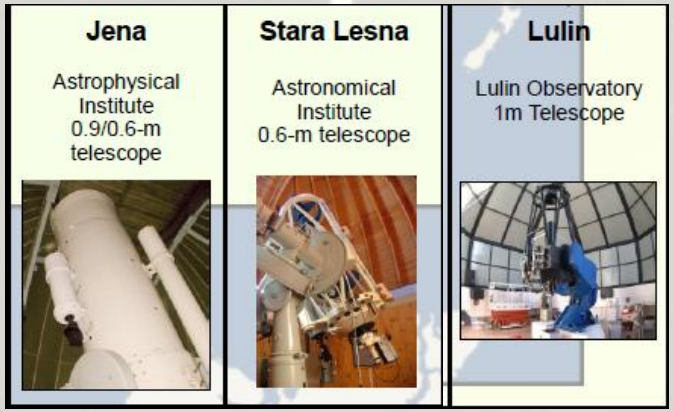
- 4th 2014.09.19 - 2014.09.26

Observatory	Observing nights
- SLO	3
- GSH	1

- 5th 2014.10.10 - 2014.10.19

Observatory	Observing nights
- SLO	3
- GSH	2





Observations and Data analysis

- Observations:

- And finally, in 2015 we also observed NGC 7243 (campaigns and add. obs.):

- 6th 2015.08.10 - 2015.08.20

Observatory	Observing nights
- SLO	4
- GSH	4

- 7th 2015.09.01 - 2015.09.14

Observatory	Observing nights
- SLO	2
- GSH	8
- LOT	3

- 8th 2015.11.16 - 2015.11.24

Observatory	Observing nights
- SLO	1
- GSH	1
- LOT	7

- Summary (campaigns)

Observatory	Observing nights
- SLO	31
- GSH	27
- LPO	19
- LOT	18

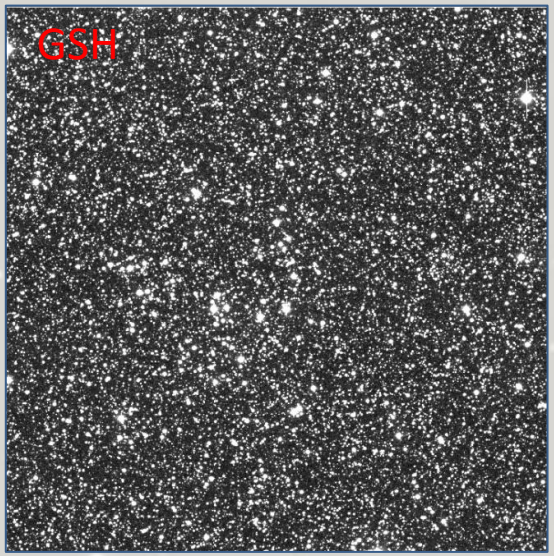
- Summary (other observations)

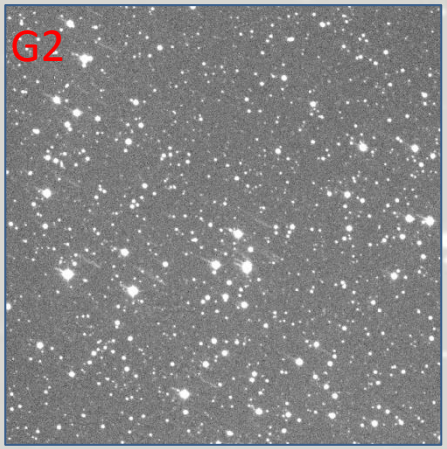
Observatory	Observing nights
- SLO	34
- GSH	23
- LPO	0
- LOT	2

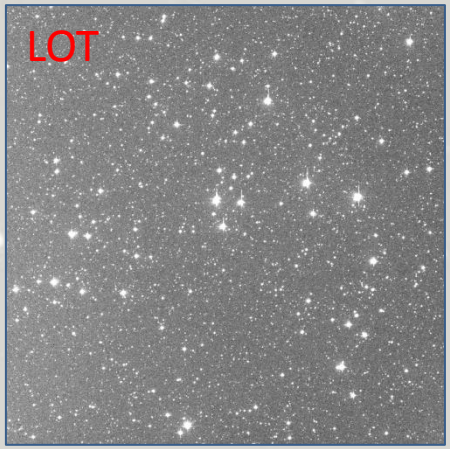
Observations and Data analysis

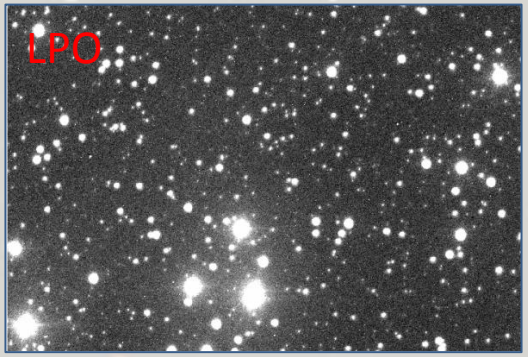
- **Observations:**
  - CCD observations were performed in ***R* filter** only:
    - short integrations: 5, 10 sec.,
    - long integrations: 80, 90 sec.
  - FoV of telescopes and amount of monitored stars:

Observatory:	FoV (arcmin):	Amount of stars:
- SLO-G1	14 x 14	1020
- SLO-G2	17 x 17	1819
- GSH	53 x 53	19461
- LPO	10 x 07	317
- LOT	22 x 21	6484







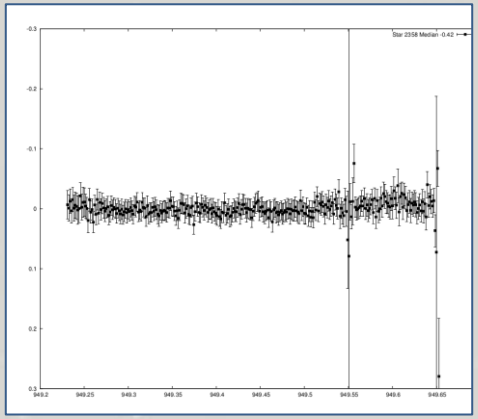


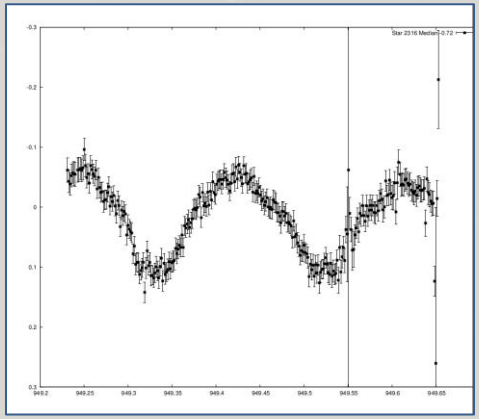
Observations and Data analysis

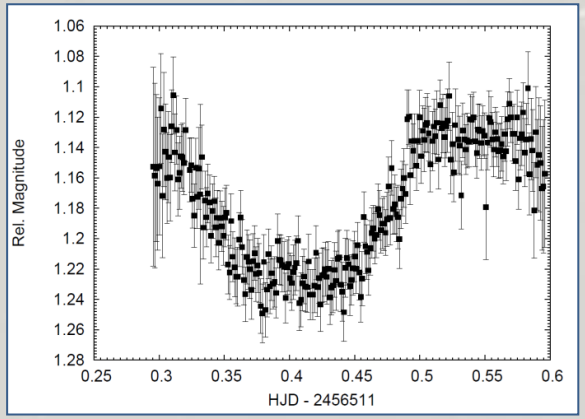
- **Data analysis:**

IRAF: Dark- and Flat-correction, overscan → **Source Extractor**: Astrometry → **IRAF**: Aperture photometry → **Broeg et al. (2005)**: Differential photometry

- All stars in the field were used to create an artificial standard star, but the more photometrical stable stars were assigned higher weights. **The artificial star was used to calculate differential magnitudes of all objects.**
- We visually inspected the data and **selected the objects showing variability**.

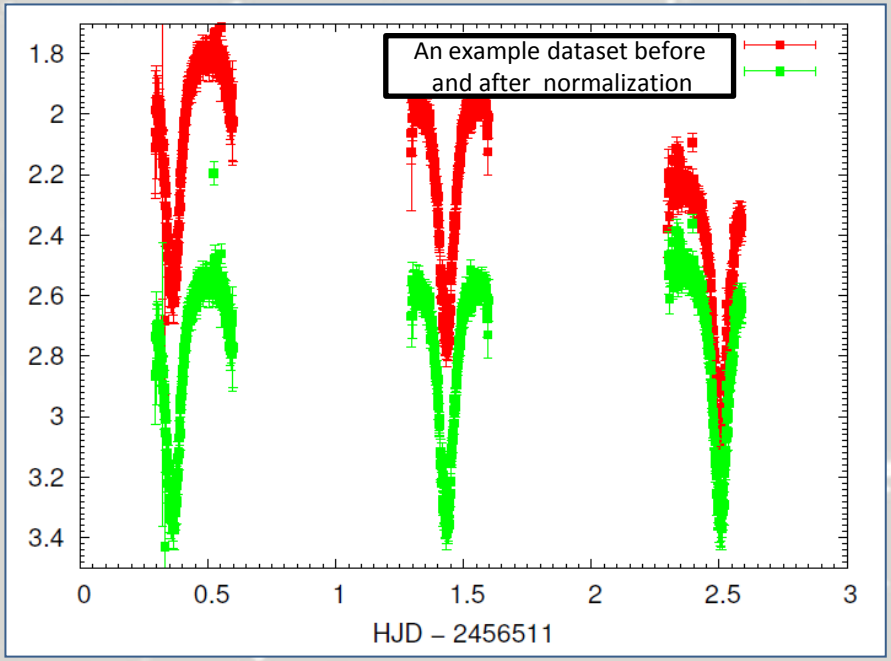


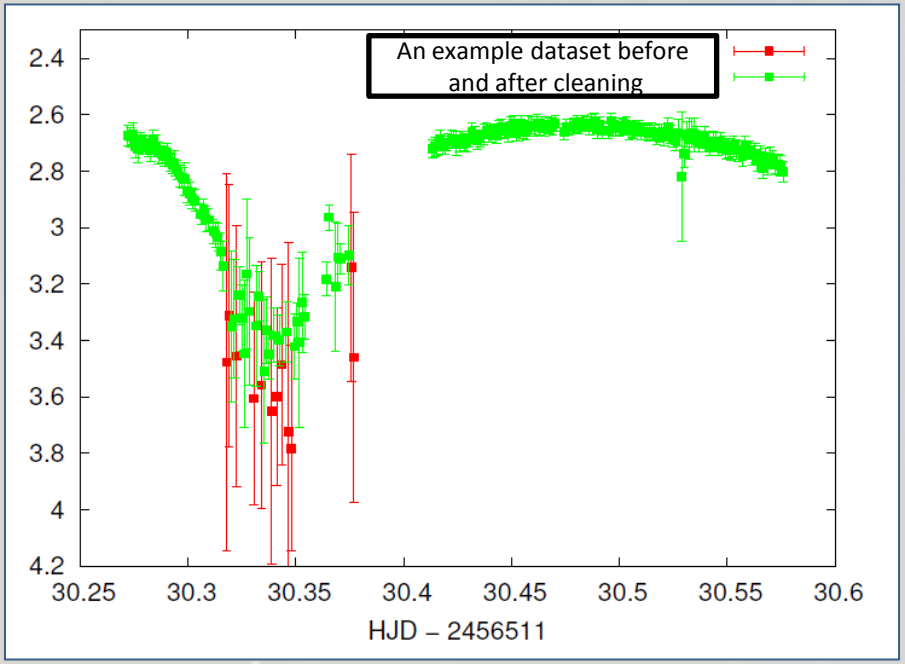




Observations and Data analysis

- **Data analysis:**
  - Due to different amount of stars included in night-to-night FoV, **extracted light curves for individual objects showed night-to-night magnitude offsets** within certain telescope data, as well. **These offsets were determined using a bright and photometrical stable star** near the center of telescope FoV.
  - **We cleaned the data** from outliers and from data points with big individual error.





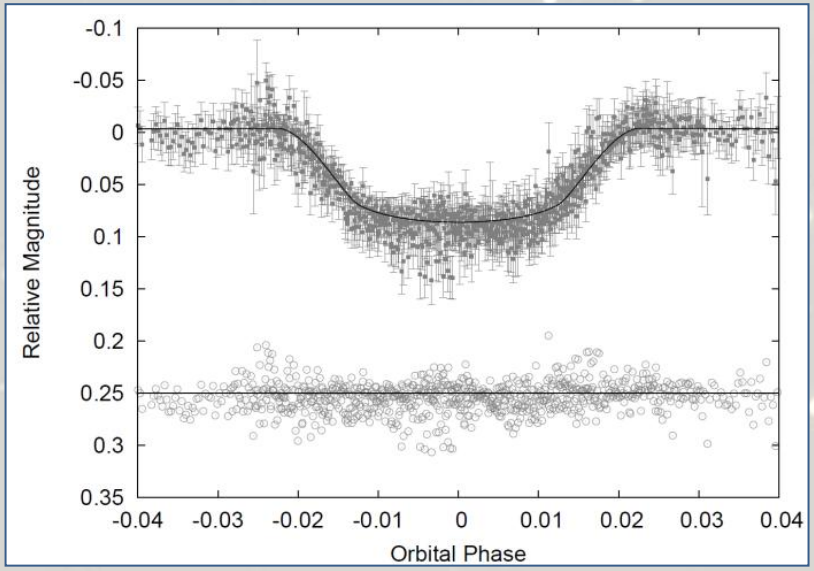
Observations and Data analysis

- **Data analysis:**

Exoplanet transit-like signals

JKTEBOP:
Final best-fit parameters

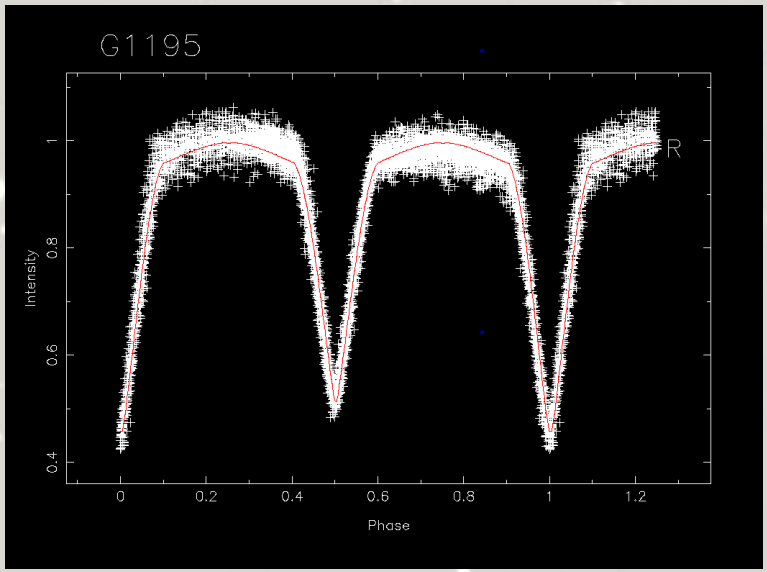
P_{orb}, i, $(R_p+R_s)/a$, R_p/R_s, T_0, c_1, c_2, L_{sf} (8 param.)



Eclipsing binary stars

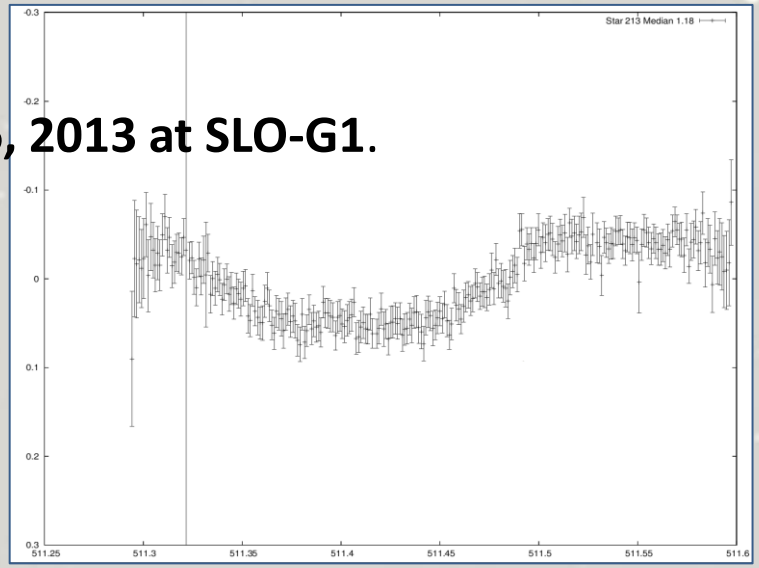
ROCHE:
Final best-fit parameters

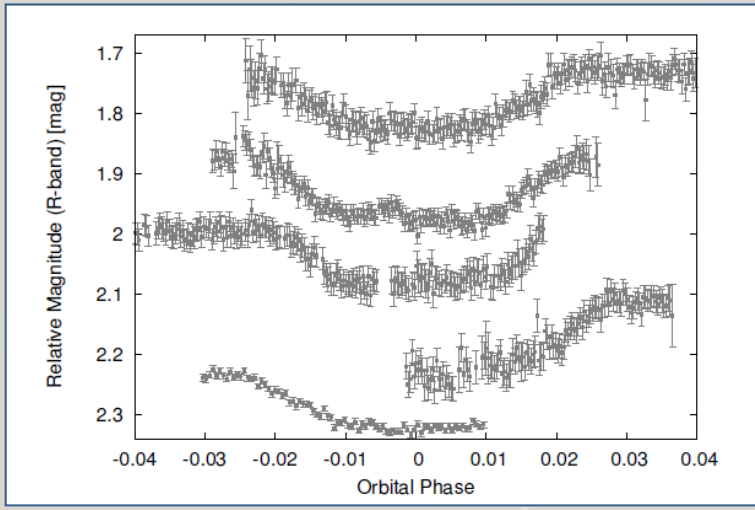
P_{orb}, T_0, i, r_1, r_2, T_2, f, q (8 param.)



Results

- **The exoplanet candidate J221550.6+495611b:**
  - The discovery detection was made on **August 6, 2013 at SLO-G1**.
  - 6 more detections were registered later:
    - October 2, 2013 at GSH,
    - **July 18, 2014 at SLO-G1**,
    - September 13, 2014 at LOT,
    - October 5, 2014 at SLO-G2,
    - **October 18, 2014 at SLO-G1**,
    - **October 18, 2014 at GSH**,
  - but only 4 observations covered the full transit.
  - 5 transits were published in Garai et al. 2016.
  - The transit light curve has a U-shape, which is typical for transits of exoplanets.
  - $R \approx 15$ mag
  - $\Delta R \approx 70 - 80$ mmag
  - $P \approx 4.380$ days

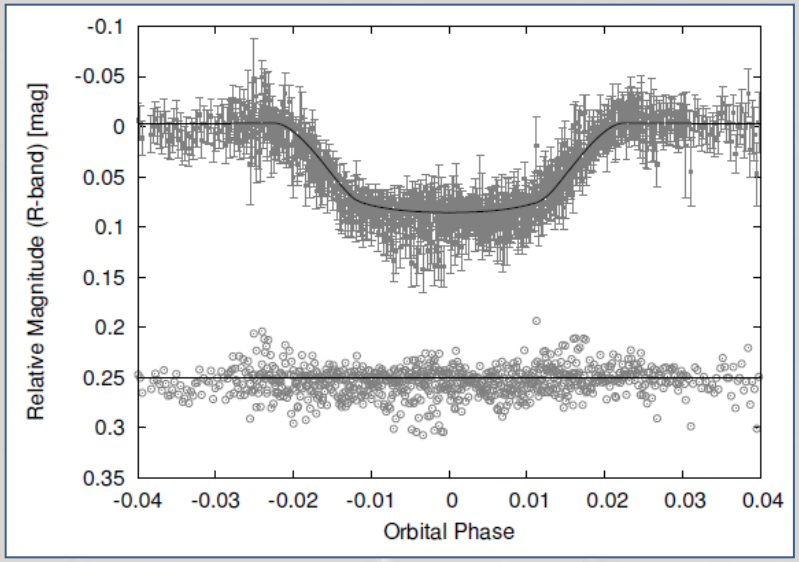




Results

- **The exoplanet candidate J221550.6+495611b:**
  - **We fitted the transit light curves simultaneously** with the JKTEBOP code and obtained the best-fit parameters:

Parameter	JKTEBOP Value
P_{orb} [d]	4.380383(12)
i [°]	87.7(4)
a/R_s	–
$(R_p + R_s)/a$	0.144(3)
R_p/R_s	0.262(2)
T_c [2 456 000 + HJD]	511.4145(7)
LD linear coeff.	0.2689
LD non-linear coeff.	0.3225
Light-scale ft. [mag]	–0.0036(9)



  - **The derived value of the parameter R_p/R_s = 0.26 is unusually large for an extrasolar planet**,
  - except, if the parent star is a dwarf star: a K-type star or an M-type star,
  - or if the parent star is a young star (a member of the open cluster NGC 7243).

Results

- **The exoplanet candidate J221550.6+495611b:**
  - **Color information:**
    - **We observed the parent star candidate in the *B* and *V* bands at SLO-G2.**
    - After the transformation to the international photometric system we obtained for the parent star candidate: ***B* = 15.48(2) mag**, ***V* = 15.03(1) mag**, and ***B – V* = 0,45(2) mag**.
    - ***B – V* = 0,45(2) mag → T_{eff} ≈ 6500 K →** an **F-type star.**
    - **The parent star is not a dwarf star** (a K-type or an M-type star).

  - **Membership information (the age of the parent star):**
    - **We used the membership catalogue compiled by Jilinsky et al. (2013)** and selected the stars with very high (99 - 96%) and high (95 - 91%) membership probabilities **and plotted the Color-Magnitude Diagram**.
    - **We re-plotted the parent star candidate onto the same CMD**.

Results

- **The exoplanet candidate J221550.6+495611b:**
  - **Membership information (the age of the parent star):**
    - **The membership of the parent star is questionable.**

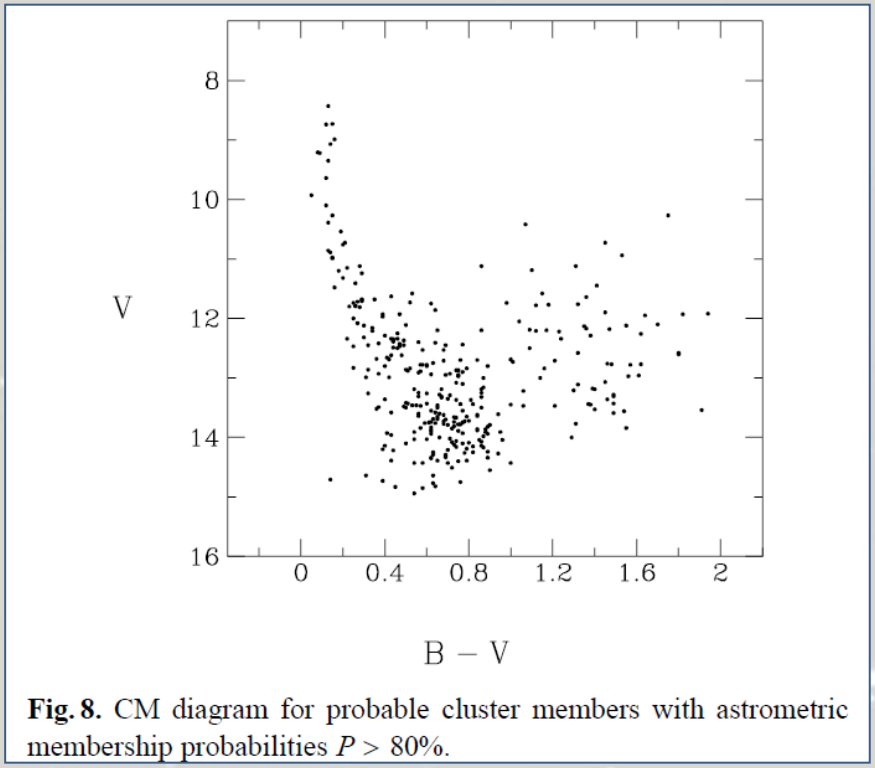


Fig. 8. CM diagram for probable cluster members with astrometric membership probabilities $P > 80\%$.

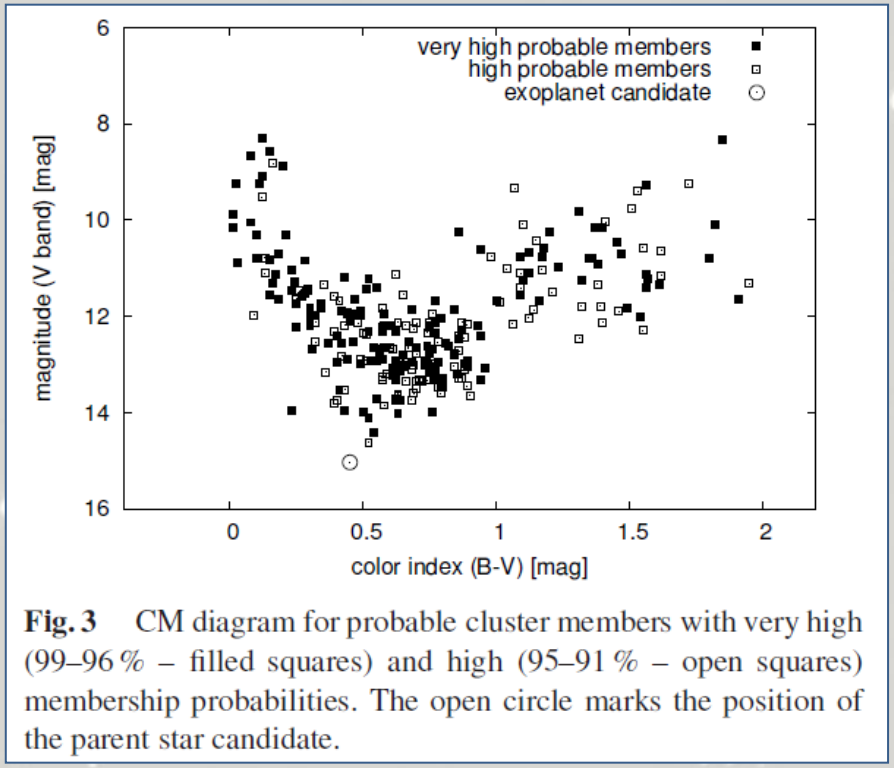


Fig. 3 CM diagram for probable cluster members with very high (99–96 % – filled squares) and high (95–91 % – open squares) membership probabilities. The open circle marks the position of the parent star candidate.

- Results published in Garai et al. 2016 (results based on 5 obs. campaigns).
- Data from campaigns Nos. 6, 7 and 8 are still unpublished ...

Results

- **The exoplanet candidate J221550.6+495611b:**

Conclusions:

- (1) This object is a hot Jupiter or brown dwarf orbiting a young star.
- (2) This object is an eclipsing binary:
    - (2a) with a dominant third star/binary in the aperture,
    - (2b) with a low-mass stellar component (F + M).

- **The planetary alternative can be confirmed by high precision RV follow-ups.**

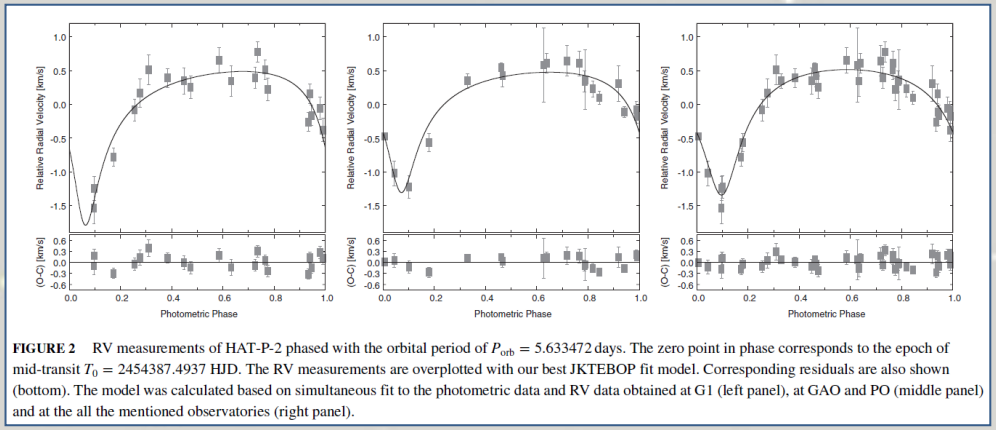


FIGURE 2 RV measurements of HAT-P-2 phased with the orbital period of $P_{orb} = 5.633472$ days. The zero point in phase corresponds to the epoch of mid-transit $T_0 = 2454387.4937$ HJD. The RV measurements are overplotted with our best JKTEBOP fit model. Corresponding residuals are also shown (bottom). The model was calculated based on simultaneous fit to the photometric data and RV data obtained at G1 (left panel), at GAO and PO (middle panel) and at the all the mentioned observatories (right panel).

The limiting magnitude at SLO-G1, SP is about 12 mag.

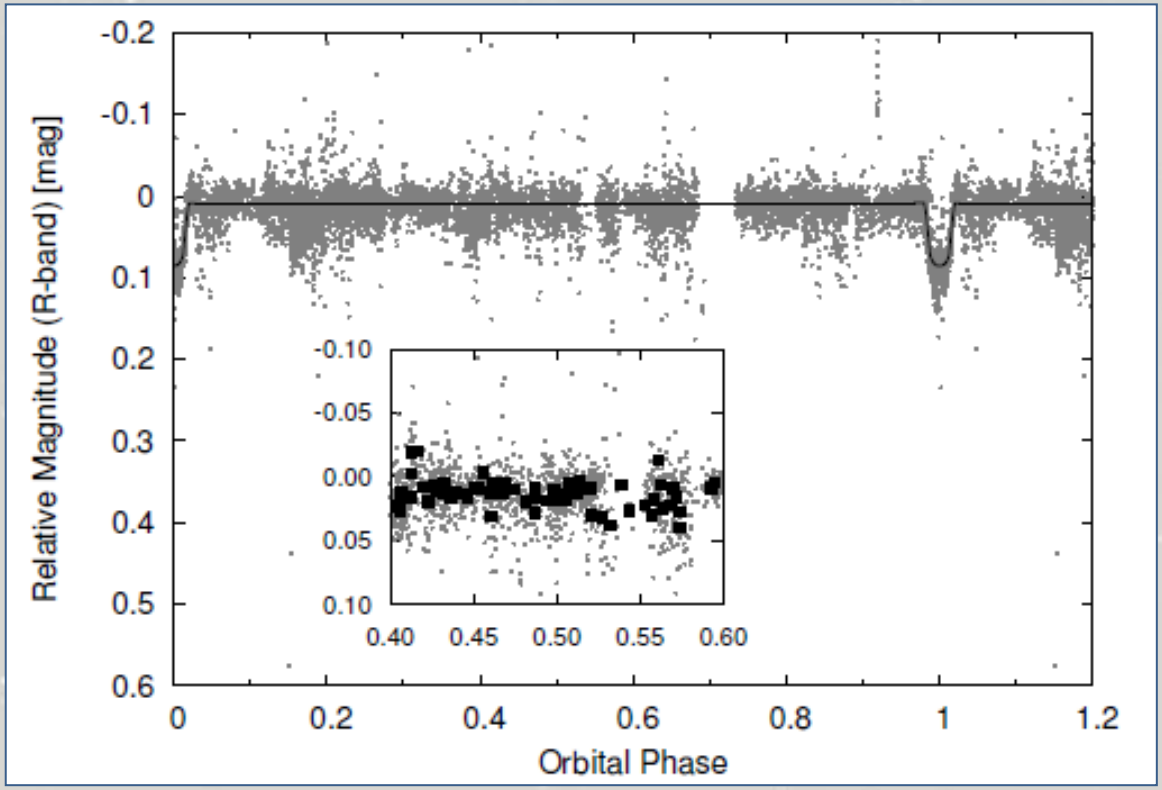
Results

- **The exoplanet candidate J221550.6+495611b:**
  - **The planetary alternative can be confirmed by high precision RV follow-ups**.
    - The target is faint: R ≈ 15 mag → we need a big telescope (6 - 10 m).


  - **Another possibility is to check indicators of eclipsing binary alternative**:
    - **Direct imaging** can rule out the third-light-in-the-aperture alternative → we need a big telescope (8 - 10 m).
    - **We can search for a secondary eclipse in the data**, a small dip roughly at the phase 0.5 (in the case of the circular orbit) is in favor of the EB alternative.
    - **We can perform multicolor observations (e.g. in two filters: *B* and *I*)** and check the transit shape and transit depth in different filters.

Results

- **The exoplanet candidate J221550.6+495611b:**
  - **Another possibility is to check indicators of eclipsing binary alternative**:
    - **We can search for a secondary eclipse in the data**, a small dip roughly at phase 0.5 (in the case of the circular orbit) is in favor of the EB alternative.
    - The secondary eclipse is not visible in this plot (Garai et al. 2016).



Results

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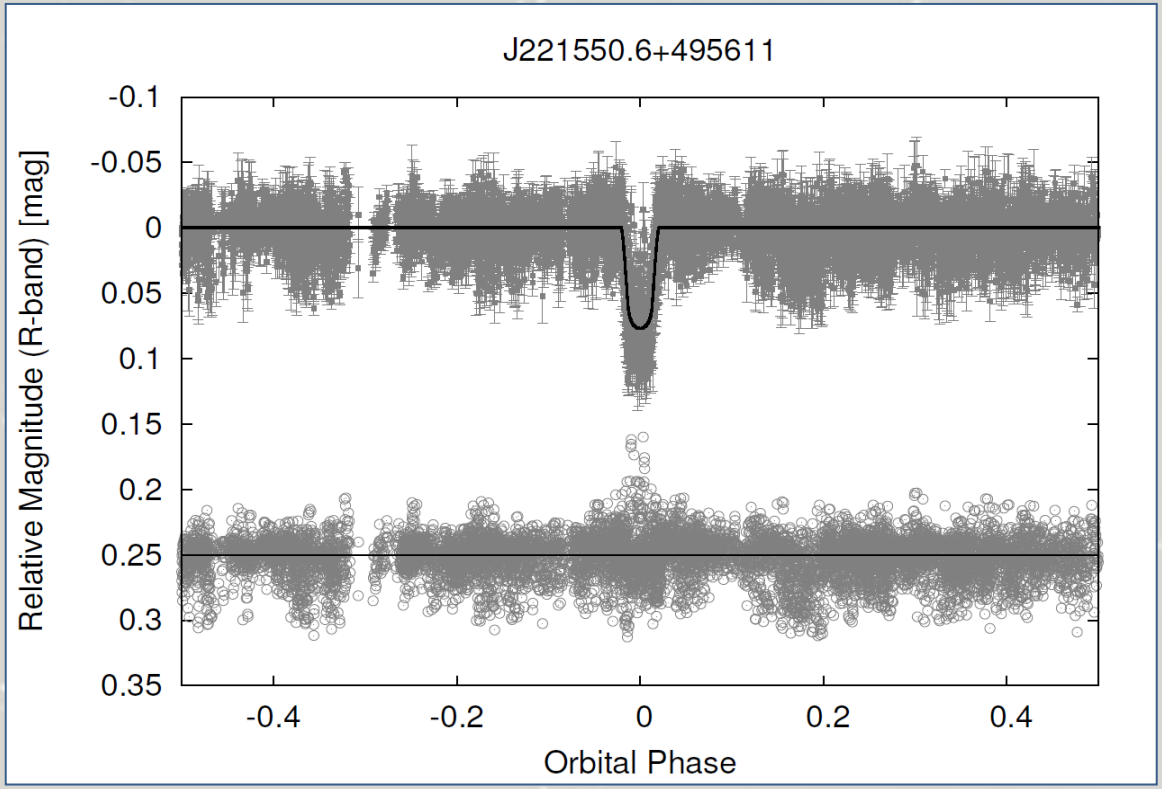
    - The secondary eclipse is not visible in this plot (Garai et al. 2016).
    - If we include new data ...



Results

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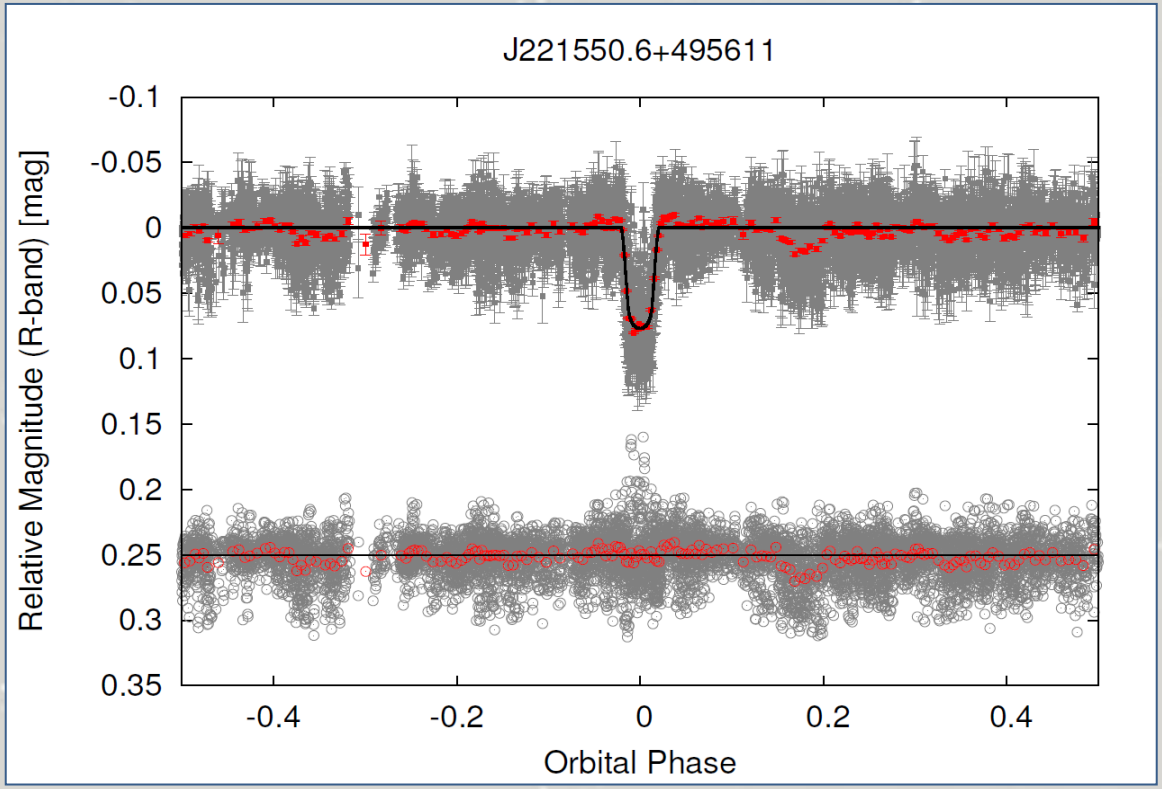
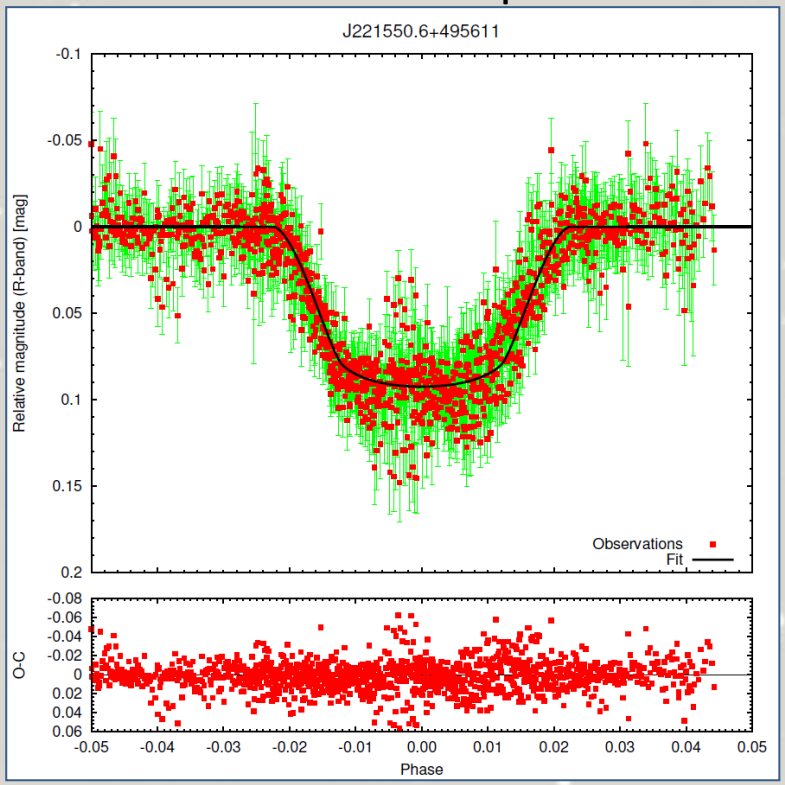
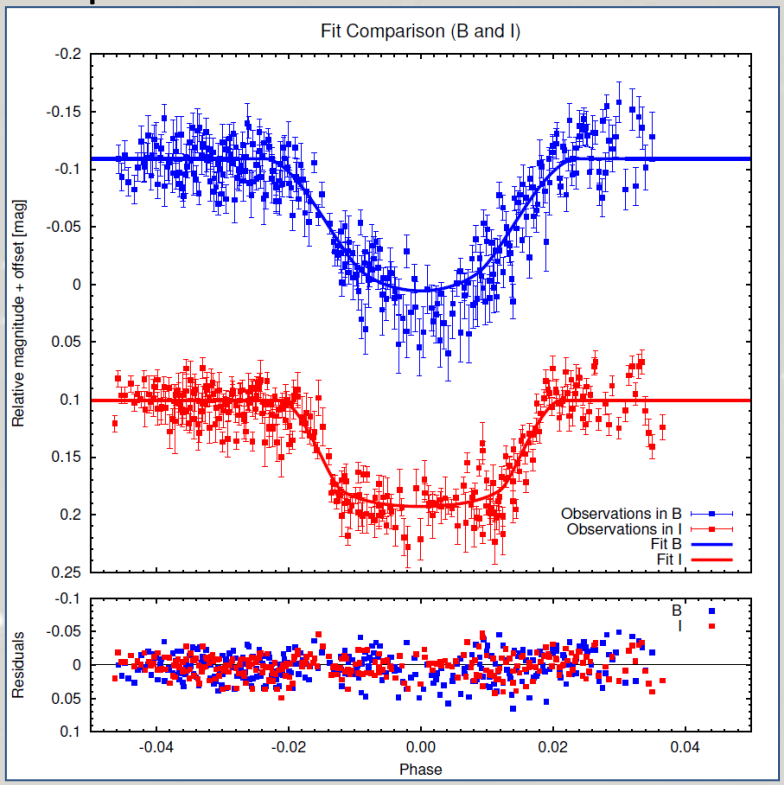
    - **We can search for a secondary eclipse in the data**, a small dip roughly at phase 0.5 (in the case of the circular orbit) is in favor of the EB alternative.
    - The secondary eclipse is not visible in this plot (Garai et al. 2016).
    - If we include new data and if we apply data binning → **a secondary-eclipse-like feature** is visible at the phase 0.2.
    - **An eccentric binary star?**



Results

- **The exoplanet candidate J221550.6+495611b:**
  - **Another possibility is to check indicators of eclipsing binary alternative**:
    - **We can perform multicolor observations (e.g. in two filters: *B* and *I*)** and check the transit shape and transit depth in different filters.

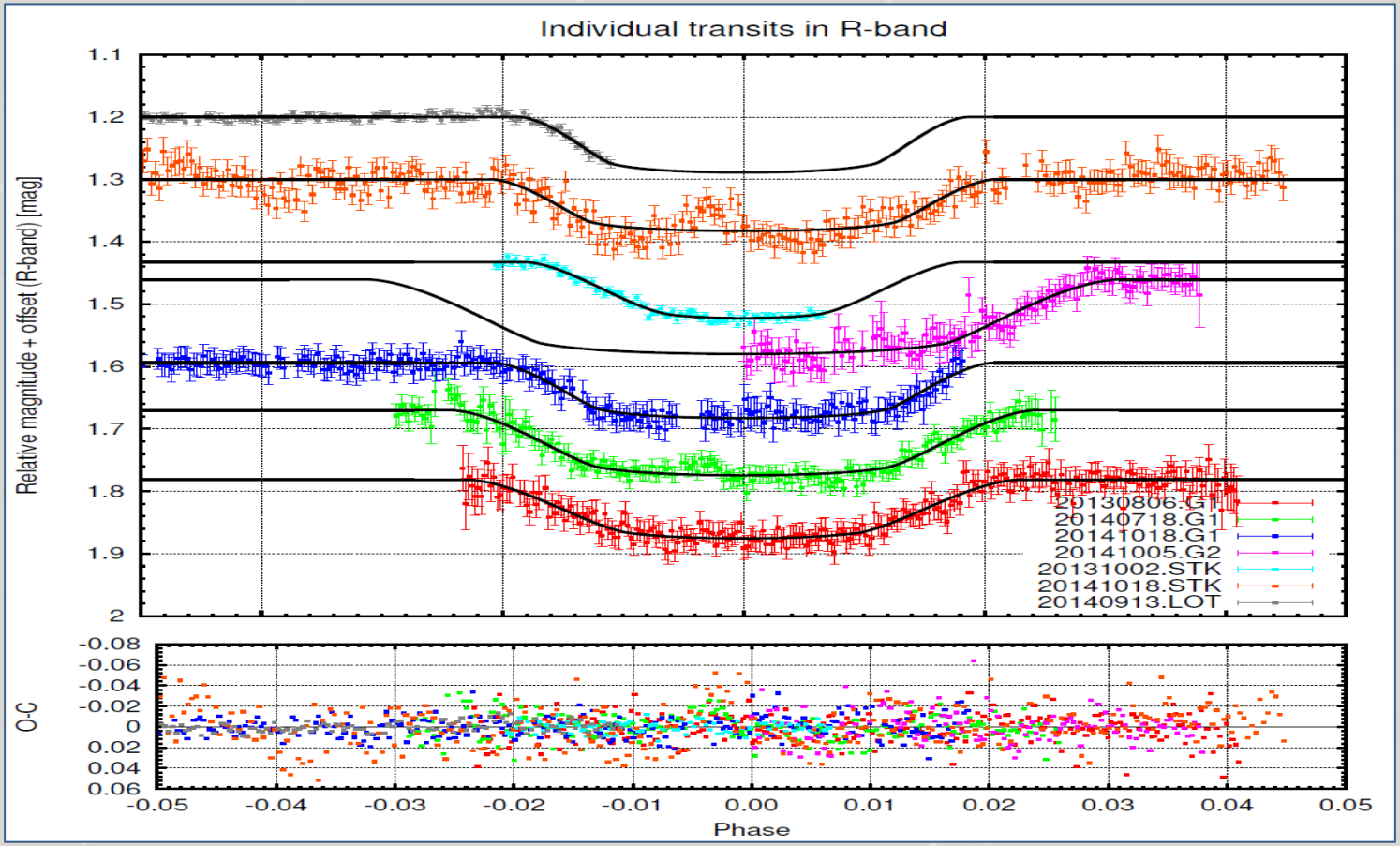




  - **There is a significant transit shape/depth difference in *B* and *I* filters …**

Results

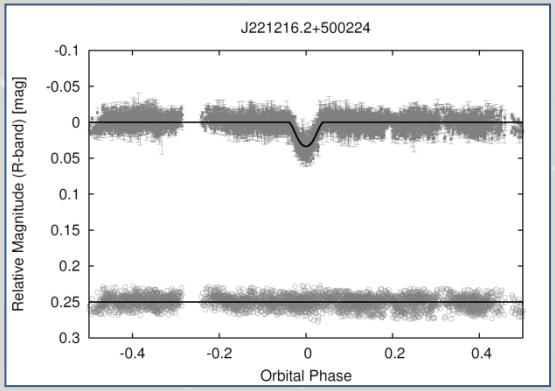
- **The exoplanet candidate J221550.6+495611b:**
  - **There is an indication of duration variations in transits (TDV) ...**

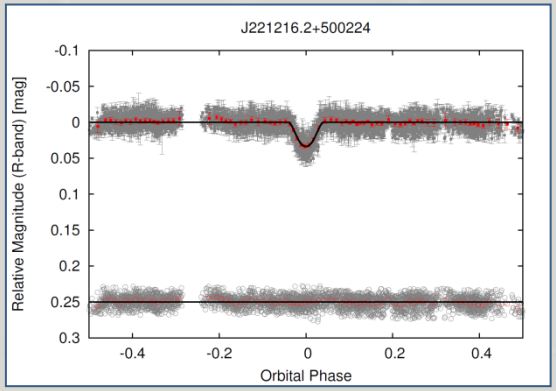


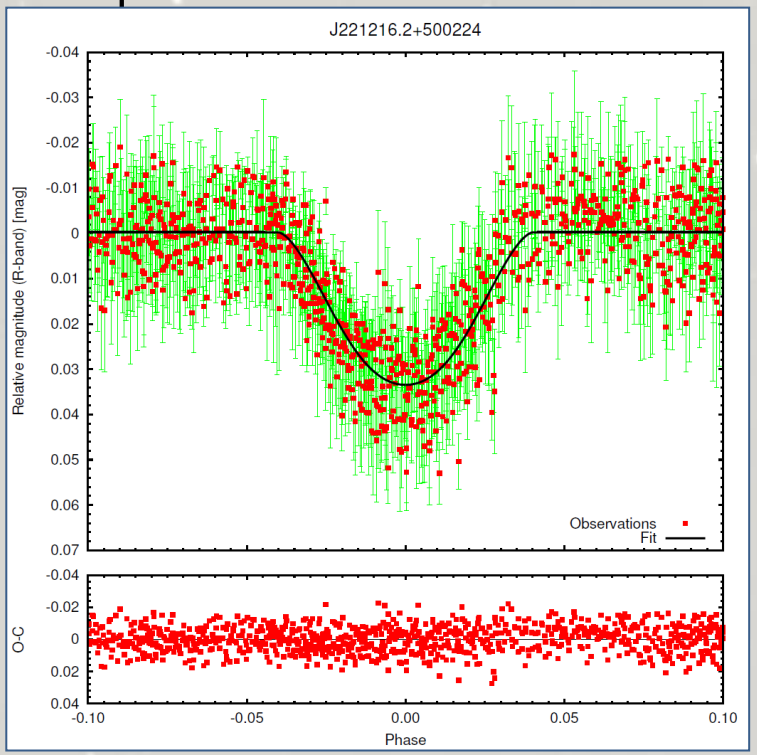
Results

- **New exoplanet candidates:**
  - Because in a few cases we detected only one eclipse/transit, we observed NGC 7243 also in 2015 during three additional campaigns.
  - Using data from all observations **we were able to identify three additional transiting exoplanet candidates** in the field of the open stellar cluster NGC 7243.
    - **J221216.2+500224b:**
      - $R \approx 14.5$ mag,
      - $\Delta R \approx 35$ mmag,
      - $P = 1.38894872$ days,
      - V-shaped transit, secondary at 0.5?

The 1st NEW





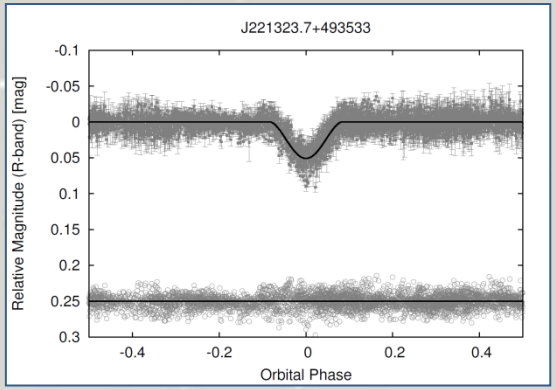


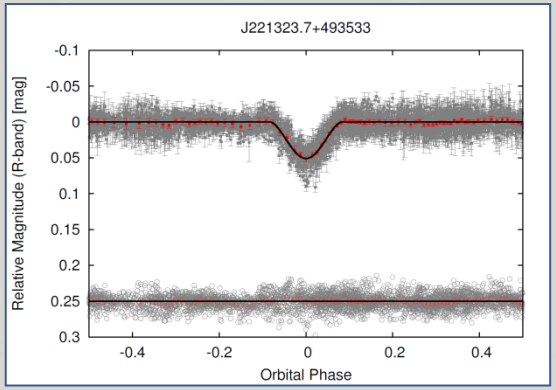
Results

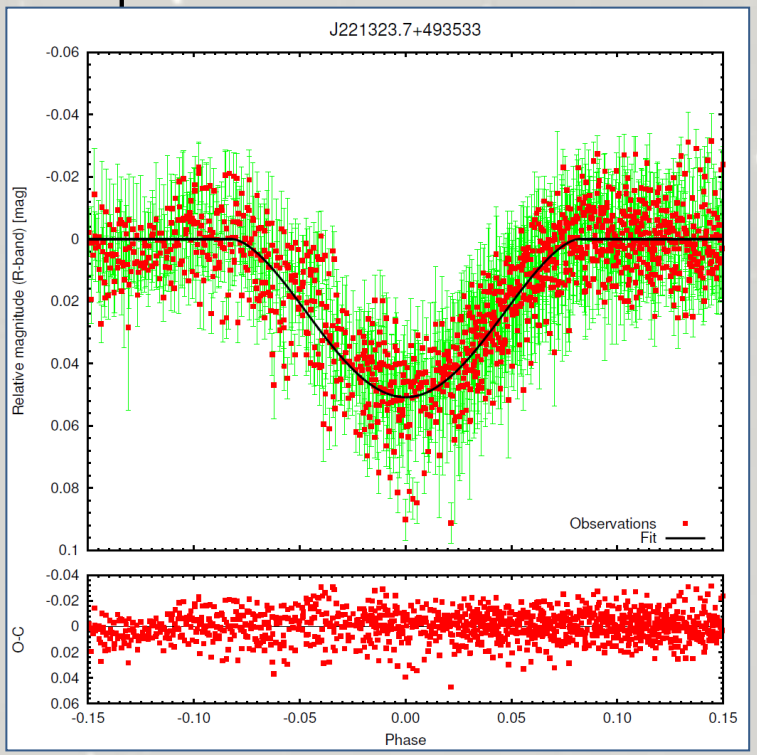
- **New exoplanet candidates:**
  - Because in a few cases we detected only one eclipse/transit, we observed NGC 7243 also in 2015 during three additional campaigns.
  - Using data from all observations **we were able to identify three additional transiting exoplanet candidates** in the field of the open stellar cluster NGC 7243.
    - **J221323.7+493533b:**

The 2nd NEW

- $R \approx 15.3$ mag,
- $\Delta R \approx 50$ mmag,
- $P = 0.80331425$ days,
- V-shaped transit, no secondary.





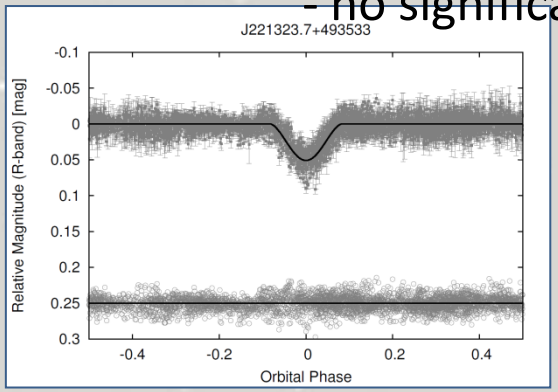


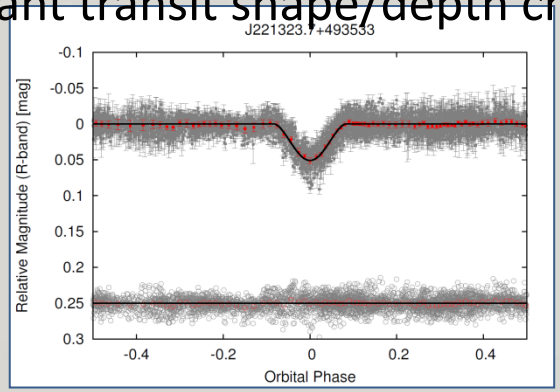
Results

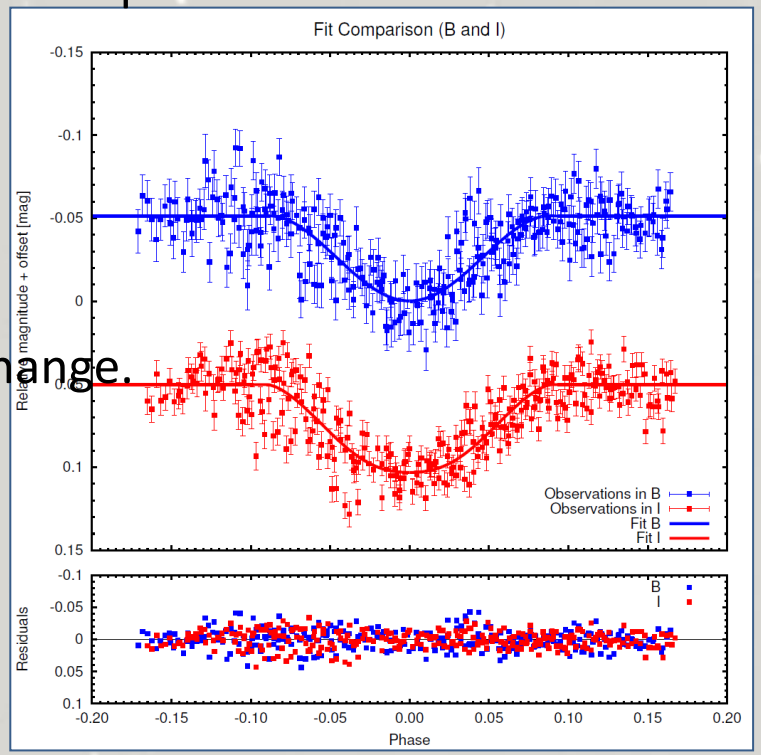
- **New exoplanet candidates:**
  - Because in a few cases we detected only one eclipse/transit, we observed NGC 7243 also in 2015 during three additional campaigns.
  - Using data from all observations **we were able to identify three additional transiting exoplanet candidates** in the field of the open stellar cluster NGC 7243.
    - **J221323.7+493533b:**

The 2nd NEW

- $R \approx 15.3$ mag,
- $\Delta R \approx 50$ mmag,
- $P = 0.80331425$ days,
- V-shaped transit, no secondary,
- no significant transit shape/depth change.





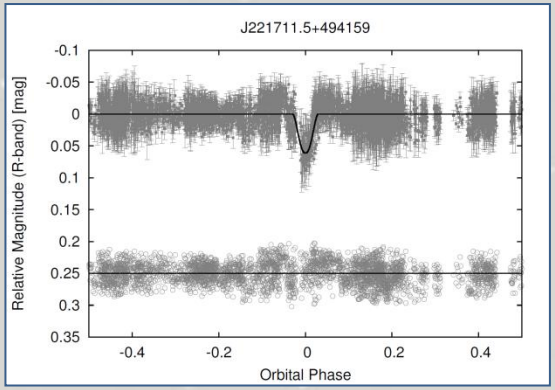


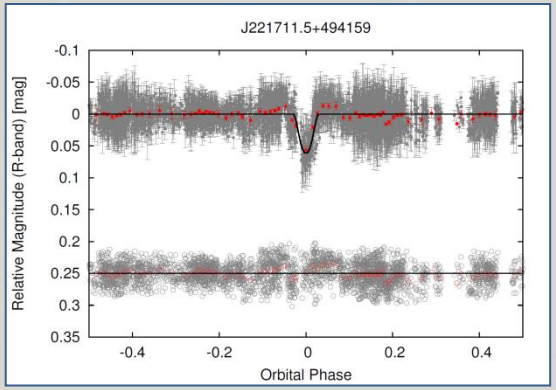
Results

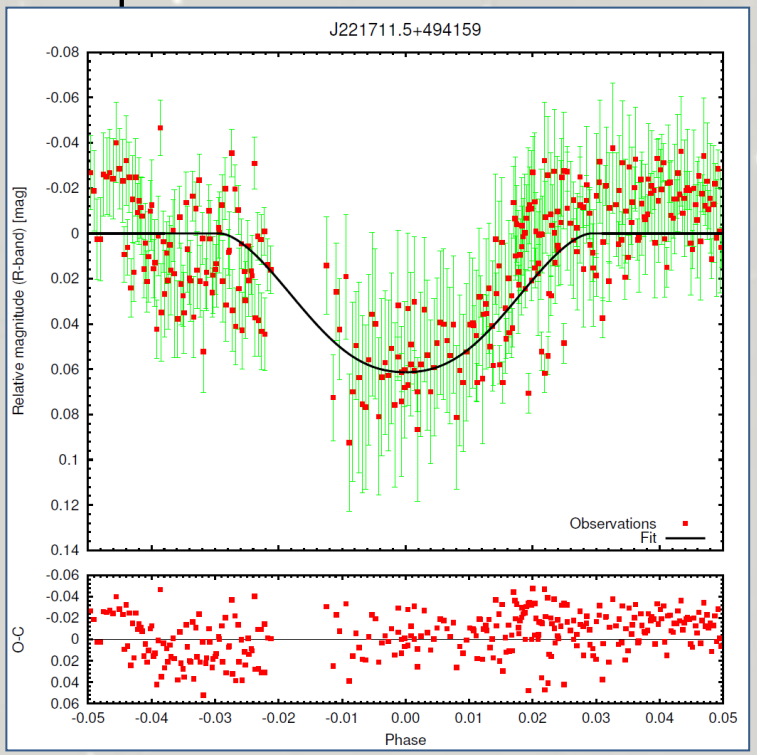
- **New exoplanet candidates:**
  - Because in a few cases we detected only one eclipse/transit, we observed NGC 7243 also in 2015 during three additional campaigns.
  - Using data from all observations **we were able to identify three additional transiting exoplanet candidates** in the field of the open stellar cluster NGC 7243.
    - **J221711.5+494159b:**

The 3rd NEW

- $R \approx 14.7$ mag,
- $\Delta R \approx 60$ mmag,
- $P = 2.85696477$ days,
- V-shaped transit, no secondary?







Results

- New exoplanet candidates:
  - Membership information (the age of the parent stars):
    - The membership of the parent stars is questionable.

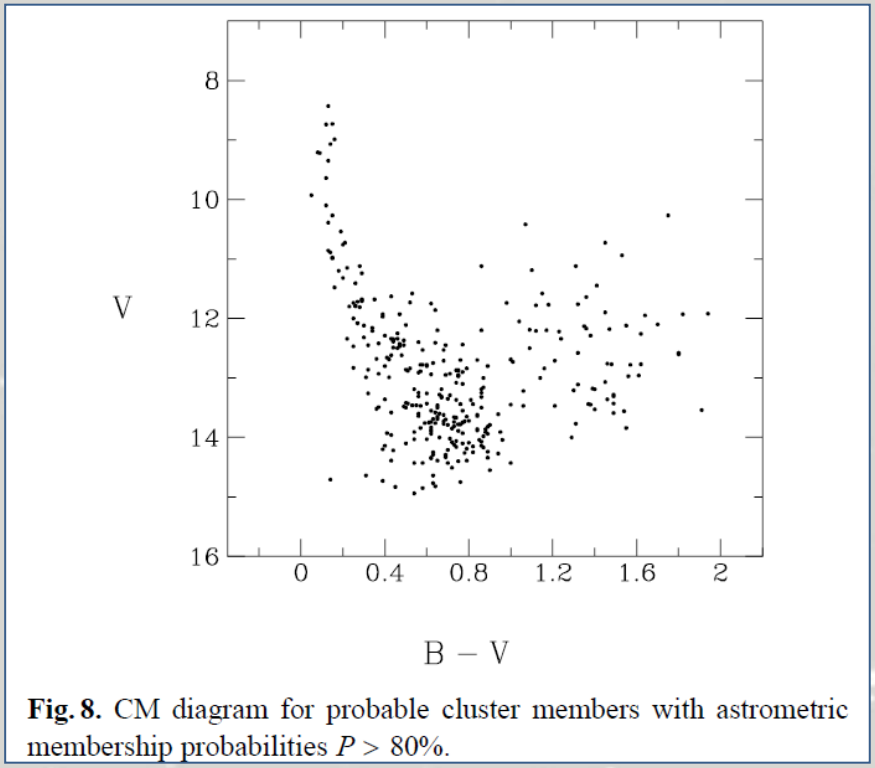
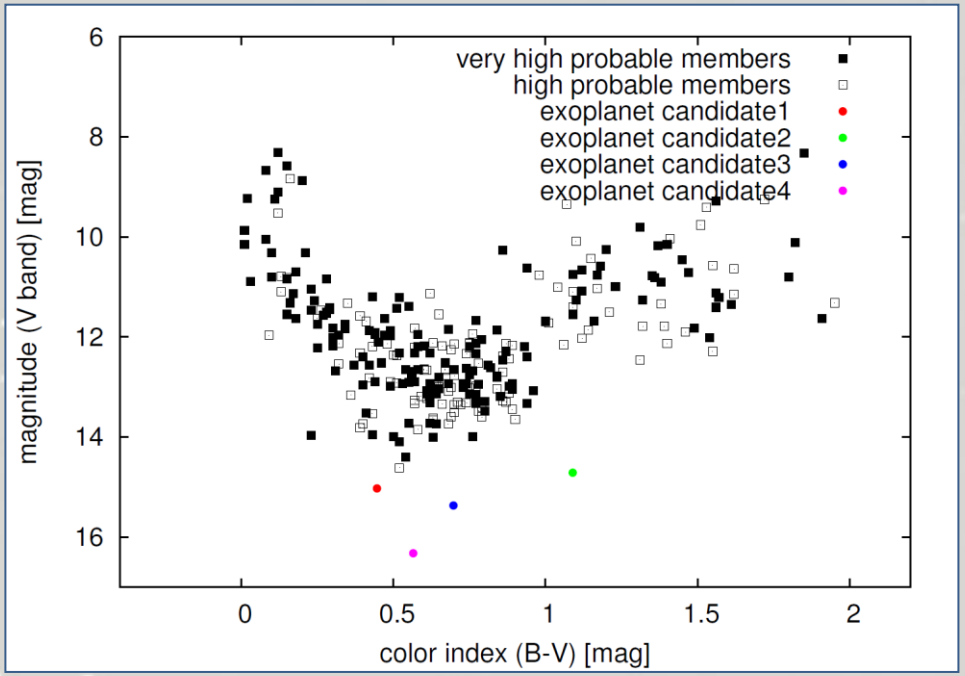
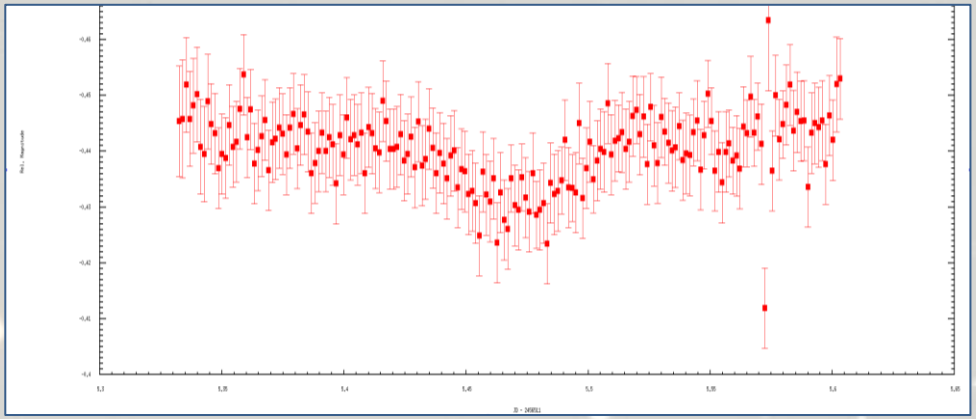


Fig. 8. CM diagram for probable cluster members with astrometric membership probabilities $P > 80\%$.

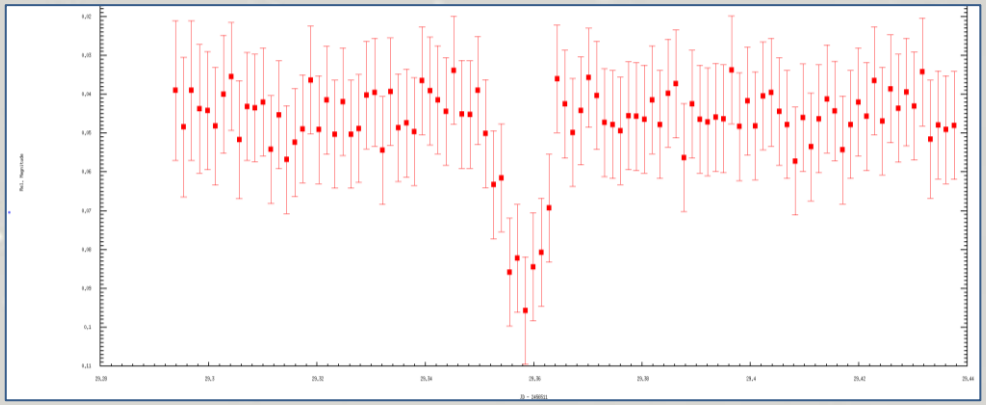


Results

- **Single transit-like features:**
  - **In two cases we still have only a single eclipse/transit.**
  - We need more observations to determine the orbital period.
    - **J221628.0+495150b:**
      - $R \approx 14.3$ mag,
      - $\Delta R \approx 20$ mmag,
      - P = ??? days.

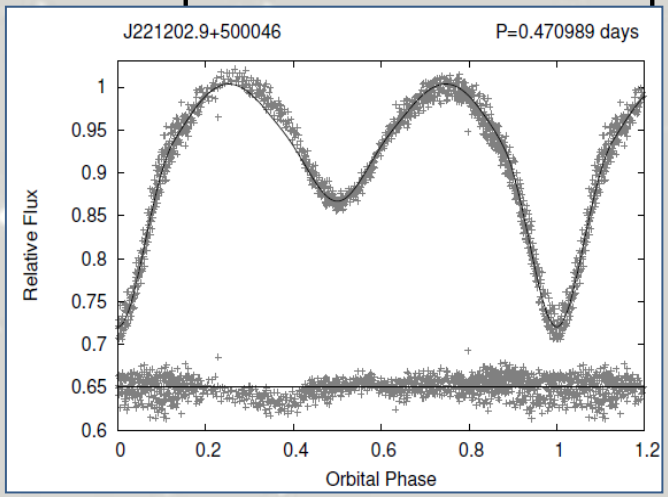


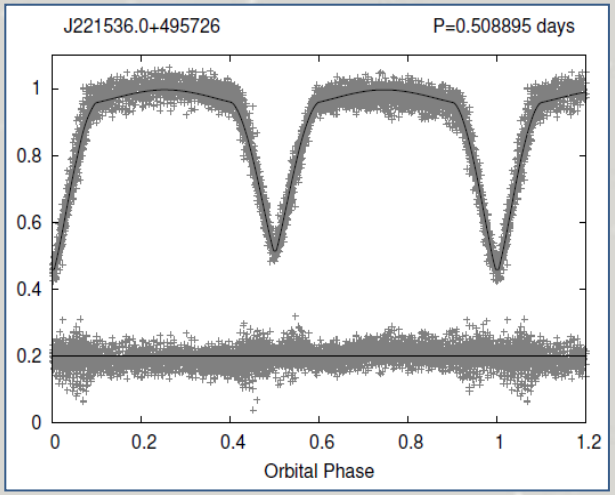
    - **J221259.4+494552b:**
      - $R \approx 15.4$ mag,
      - $\Delta R \approx 50$ mmag,
      - P = ??? days.

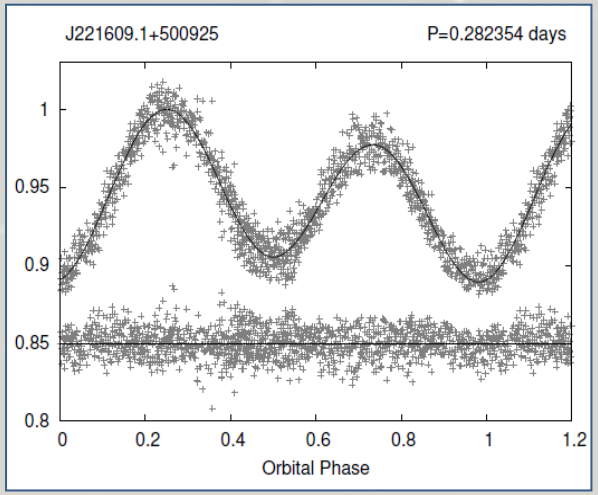


Results

- **Eclipsing binary stars:**
  - **We detected and analyzed 37 new eclipsing binary stars in the studied region:**
    - **22 detached eclipsing binary stars,**
    - **15 contact eclipsing binary stars (Garai et al. 2016).**
  - We derived the best fit parameters and light curves of EBs.
  - The resulting photometric elements are rather preliminary, because only one photometric band was used.
  - Multicolor photometry would improve modeling of spotted systems where temperature contrast of spots cannot be now determined.

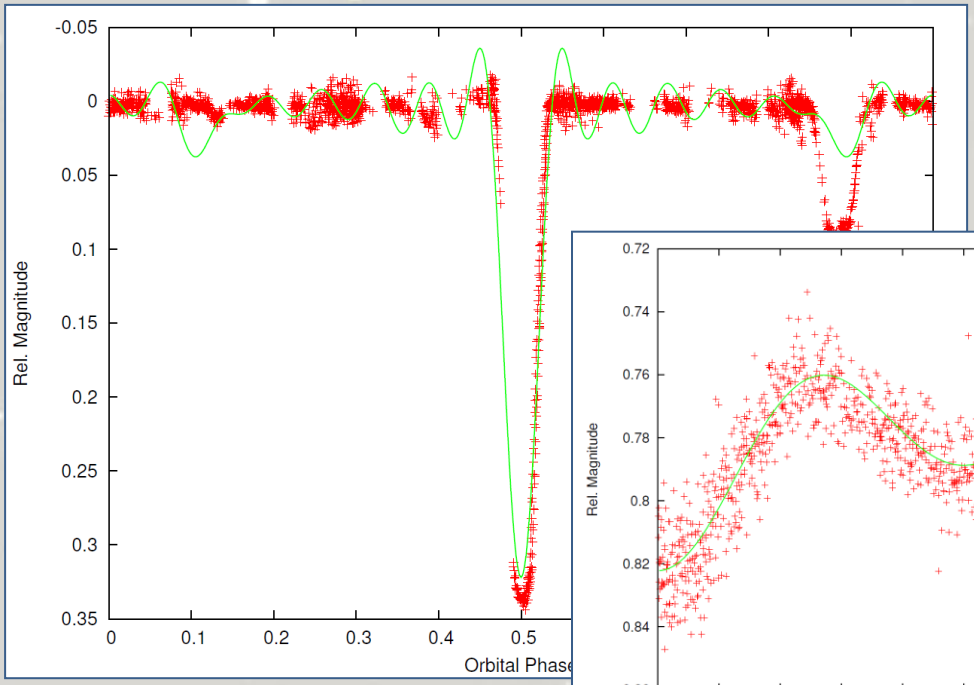


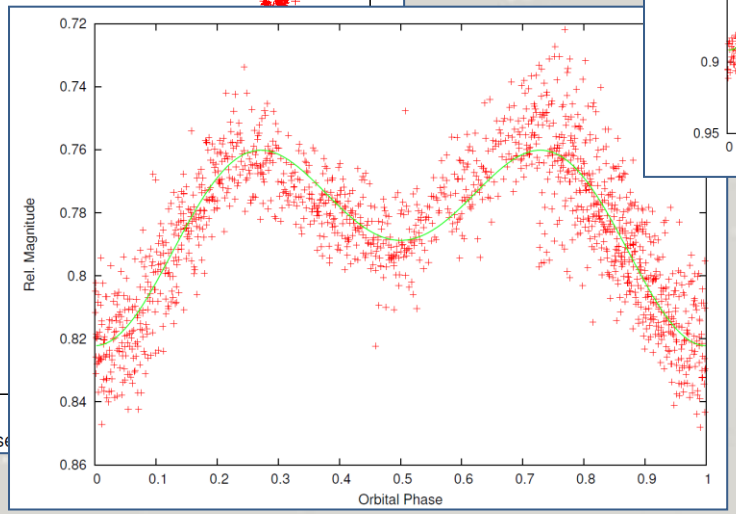


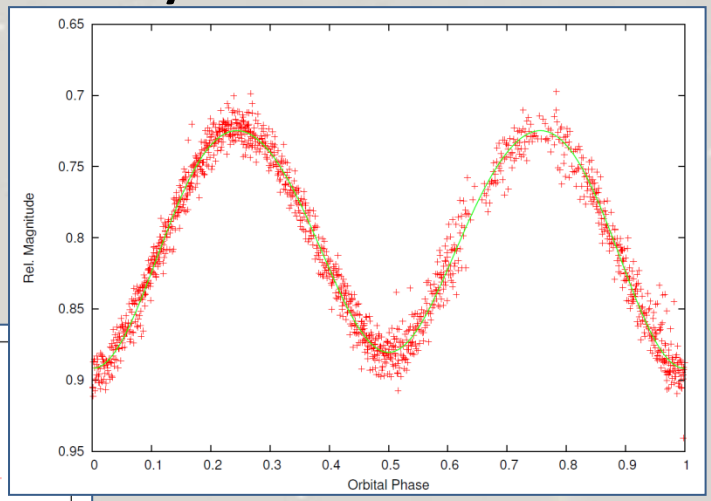


Results

- **New eclipsing binary stars:**
  - Because in a few cases we detected only one eclipse, we observed NGC 7243 also in 2015 during three additional campaigns.
  - Using data from all observations **we were able to identify additional EBs** in the field of the open stellar cluster NGC 7243.

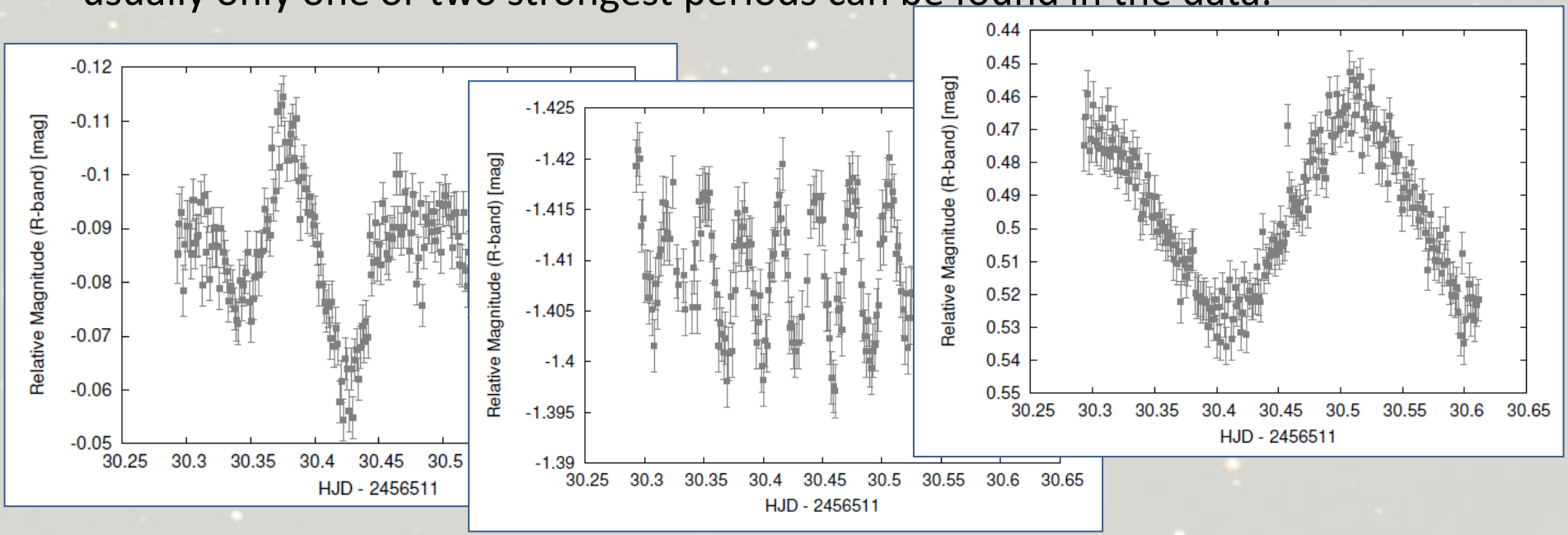






Results

- **Pulsating variable stars:**
  - **We detected and analyzed 26 new, presumably pulsating variable stars in the studied region (Garai et al. 2016):**
  - Having single-band photometry, we cannot exclude W UMa type EBs in some cases.
  - The observations are affected by lack of longer runs → poor spectral window → usually only one or two strongest periods can be found in the data.



Summary and Outlooks

- **Summary:**
  - **After 8 observing campaigns and additional observations we identified:**
    - **4 transiting exoplanet candidates with well determined orbital period,**
      - **one candidate has typical transit shape**, but a relatively deep transit,
      - **in three cases** we identified intermediately deep, but **grazing transits**,
      - we identified **secondary-eclipse-like features in two cases**,
      - we identified a **significant transit color change in one case** (up to now),
      - we identified an indication of TDVs in one case (up to now),
      - the membership of the parent stars is questionable.
    - **2 objects with a single transit-like feature,**
      - the orbital period of the objects is unknown.
    - **We also analyzed other variable stars,**
      - **37 new EBs,**
      - **26 new pulsating variable stars,**
    - **based on 8 observing campaigns we found additional EBs.**
    - **The full 8-campaign results will be published soon** (Garai et al., in prep.).

Summary and Outlooks

- **Outlooks:**
  - **The confirmation process of the exoplanet candidates would require**
    - **multicolor photometry,**
    - **direct imaging,**
    - **high-dispersion spectroscopy for radial velocities (Garai et al. 2016).**

  - We can perform **multicolor photometry of candidates at SLO-G2, SP, PO, GSH, ...**
  - direct imaging → we still need a big telescope,
  - high precision RV follow-ups →
    - 1st step: **spectral typing (or initial screening of the candidates)**, an **INT proposal was submitted, observations in Oct. – Nov. 2018** (PI: Marie Karjalainen, INT),
    - 2nd step: RV measurements → we still need a big telescope.

Thank you!

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