Systematic issues in the photometry of MPC observations leading to erroneous size estimates

Debiasing astro-photometric observations with corrections using statistics (DePhOCUS)

Tobias Hoffmann, Marco Micheli, Juan Luis Cano, Maxime Devogèle, Davide Farnocchia, Petr Pravec, Peter Vereš, Björn Poppe

Tobias Hoffmann

ESA ESOC

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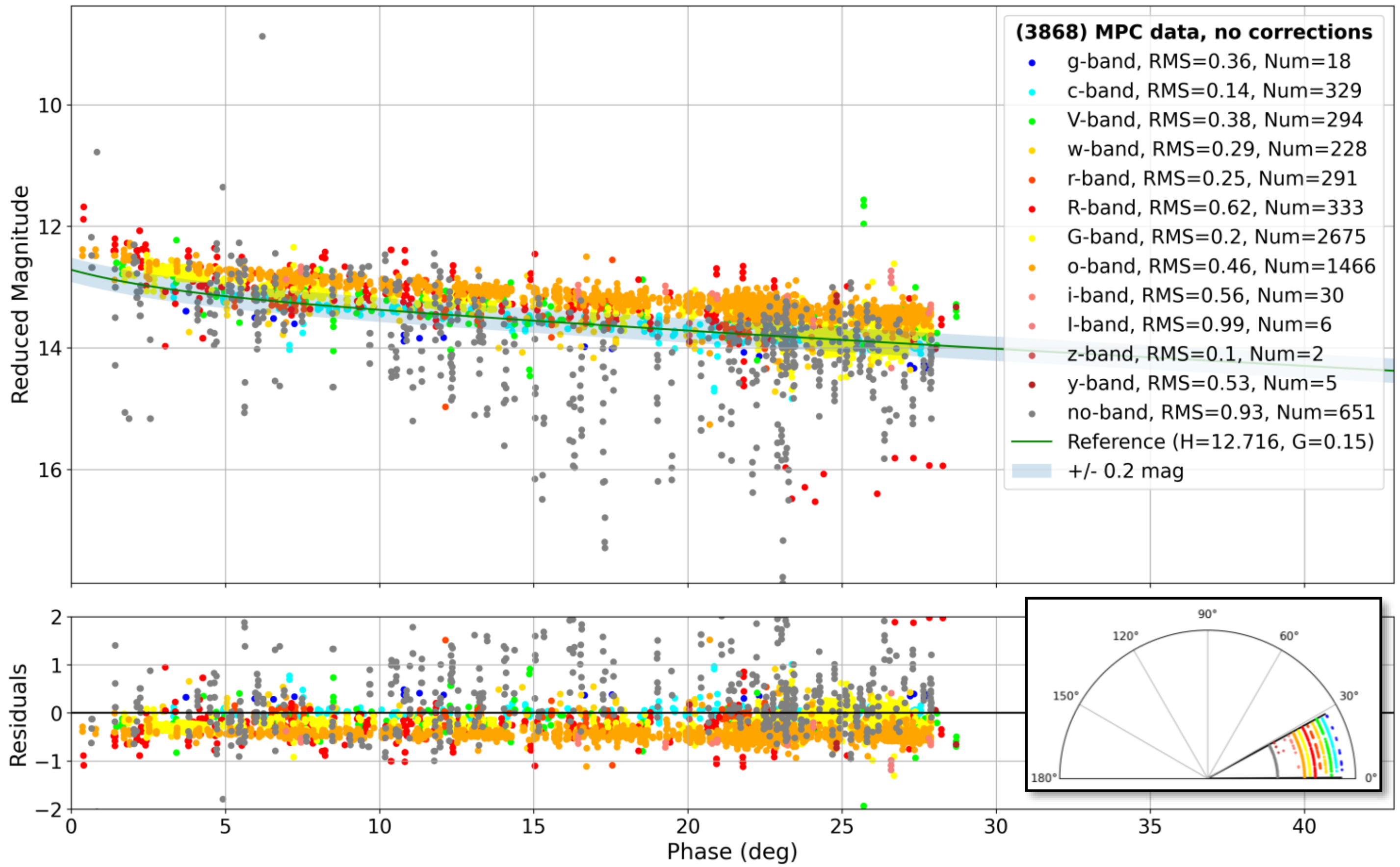
Motivation

- High photometric <u>errors</u> in MPC observations, ~0.4 mag in H-mag (Jurić et al., 2002)
    - Colour band conversion
    - Systematic measuring errors
- Challenging estimation of phase curve parameters, inaccurate <u>size</u> and other physical parameters
    - Characterization
    - Planetary Defence
- “MPC (and others) now attempt to address with observatory-dependent corrections […]” (Vereš et al., 2015)



– Multi-band astro-photometry
– Varying measuring techniques

– Intrinsic color offsets
– Observer-specific deviations

Debiasing
systematic photometric errors

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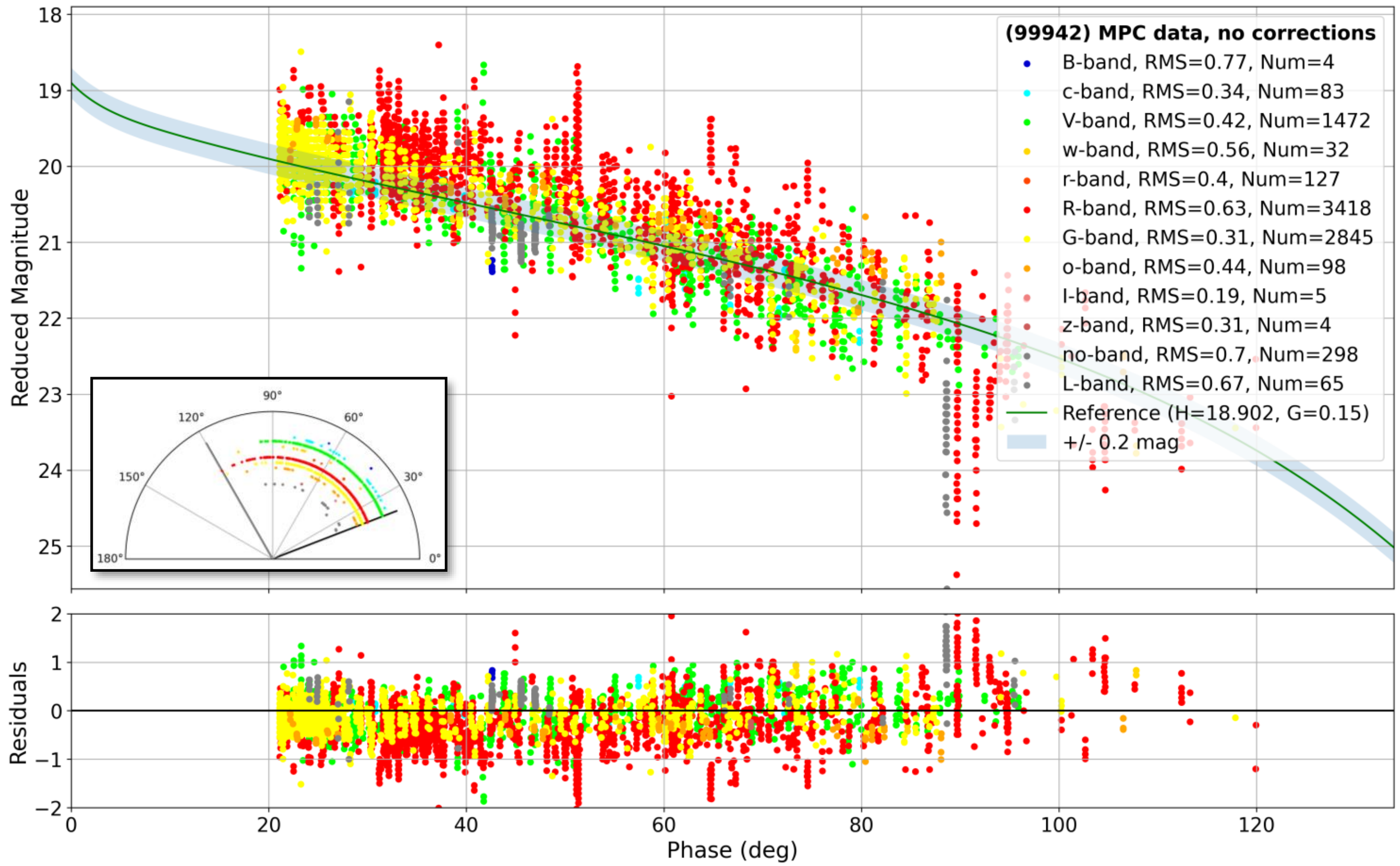

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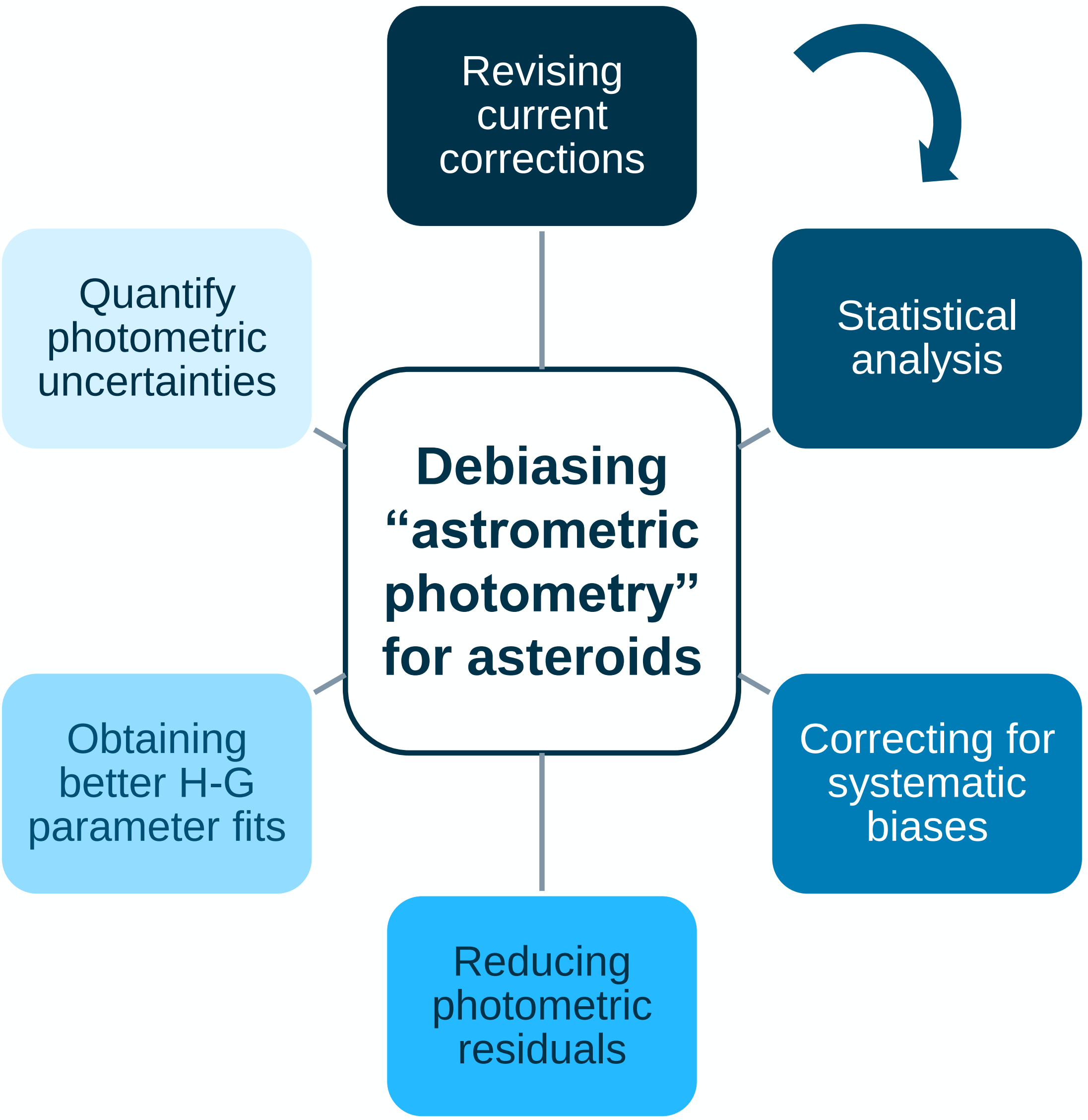
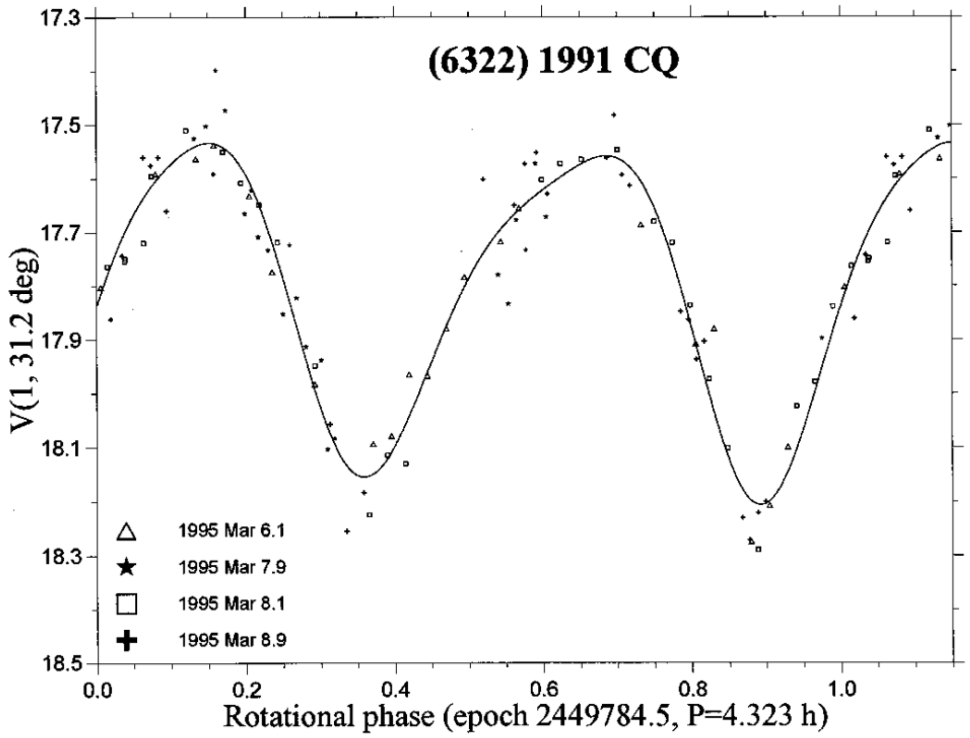

Revising current corrections
Statistical analysis
Correcting for systematic biases
Reducing photometric residuals
Obtaining better H-G parameter fits
Quantify photometric uncertainties
Debiasing "astrometric photometry" for asteroids

Method

Reference database

- Ondrejov NEO Photometric Program (Pravec et al., 1997, 2012)
  - Dataset with light- and phasecurves of NEA, Mars crossers and MBA
  - Observations from Ondrejov Observatory, La Silla and other collaborating stations
  - Including more than **500 asteroids**
  - For our study: Prepublished database* as at 11/08/2023, 468 asteroids in total (in V-band)
    - **H-G phase curve parameters** (and errors), Model by Bowell et al. (1989)
  - Absolute magnitude H is corresponds to the mean light in Johnson V or R photometric system, calibrated with Landolt (1992) standard stars

  → reduces photometric biases, especially due to rotation



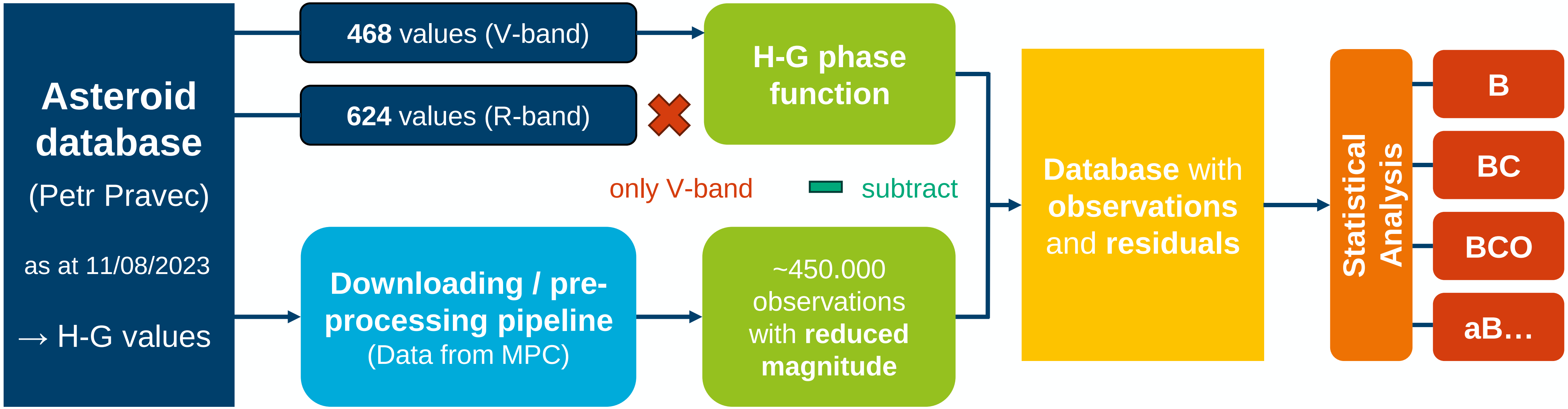
Pravec et al. (1997)

*https://www.asu.cas.cz/~ppravec/newres.htm

Method

Design of the bias analysis system

- Analysing photometric residuals with a list of objects with reliable H-G values



(Hoffmann et al., 2024)

- Obtaining systematic biases for: color band (B), photometric catalog (C), observatory (O)
- Additionally: accounting each asteroid equally to reduce selection bias (a)

Results

Bias analysis system – Color Band (B)

- Comparison of average **color-band biases** to **current correction** values
  - Modern bands (like Sloan or ATLAS): low deviation and previous corrections agree with our results
  - Majorly used bands (Johnsons-Cousins V, R and Gaia G-band): slight deviation, less accurate
  - Less typical bands (like B, I and H): high deviation, only few observations
  - Pan-STARRS w-band and unspecified band: large inconsistency

→ **New corrections needed**

General		Corrections		Debias results			
Band	Note	MPC	NEOCC	Debias aB	error	Obser-vations	Diff. to MPC
B	Johnson-Cousins	-0.80	-0.80	0.11	0.23	227	0.91
g	Sloan	-0.35	-0.28	-0.33	0.01	4.600	-0.02
c	ATLAS cyan	-0.05	-0.05	-0.02	0.01	18.980	0.03
V	Johnson-Cousins	0.00	0.00	0.08	0.02	63.520	0.08
w	Pan-STARRS	-0.13	0.16	0.11	0.01	25.582	0.24
r	Sloan	0.14	0.23	0.13	0.01	20.661	-0.01
R	Johnson-Cousins	0.40	0.40	0.28	0.02	52.887	-0.12
G	Gaia Broadband	0.28	0.28	0.15	0.02	102.697	-0.13
o	ATLAS orange	0.33	0.33	0.33	0.01	55.716	0.00
i	Sloan	0.32	0.39	0.33	0.01	5.178	0.01
I	Johnson-Cousins	0.80	0.80	0.25	0.08	137	-0.55
z	Sloan	0.26	0.37	0.29	0.02	453	0.03
y	Pan-STARRS	0.32	0.36	0.34	0.02	202	0.02
Y	1.035 micron band	0.70	0.70	0.91	0.02	36	0.21
J	1.275 micron band	1.20	1.20	1.36	0.02	69	0.16
H	1.662 micron band	1.40	1.40	1.81	0.02	20	0.41
K	2.159 micron band	1.70	1.70	1.83	0.03	39	0.13
-	No band specified	-0.80	-0.80	-0.04	0.02	50.399	0.76
u	unknown	2.50	-2.50	-2.44	0.05	20	0.06
C	"clear" formerly	0.40	0.40	0.35	0.02	976	-0.05

(Hoffmann et al., 2024)

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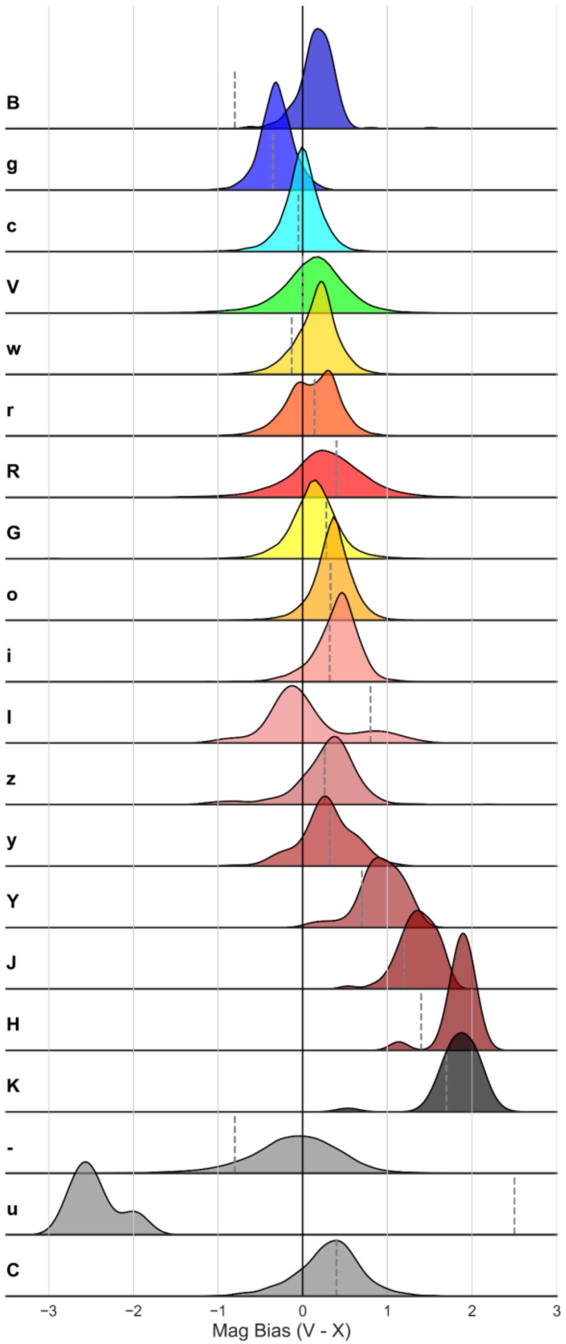


Distribution of residuals

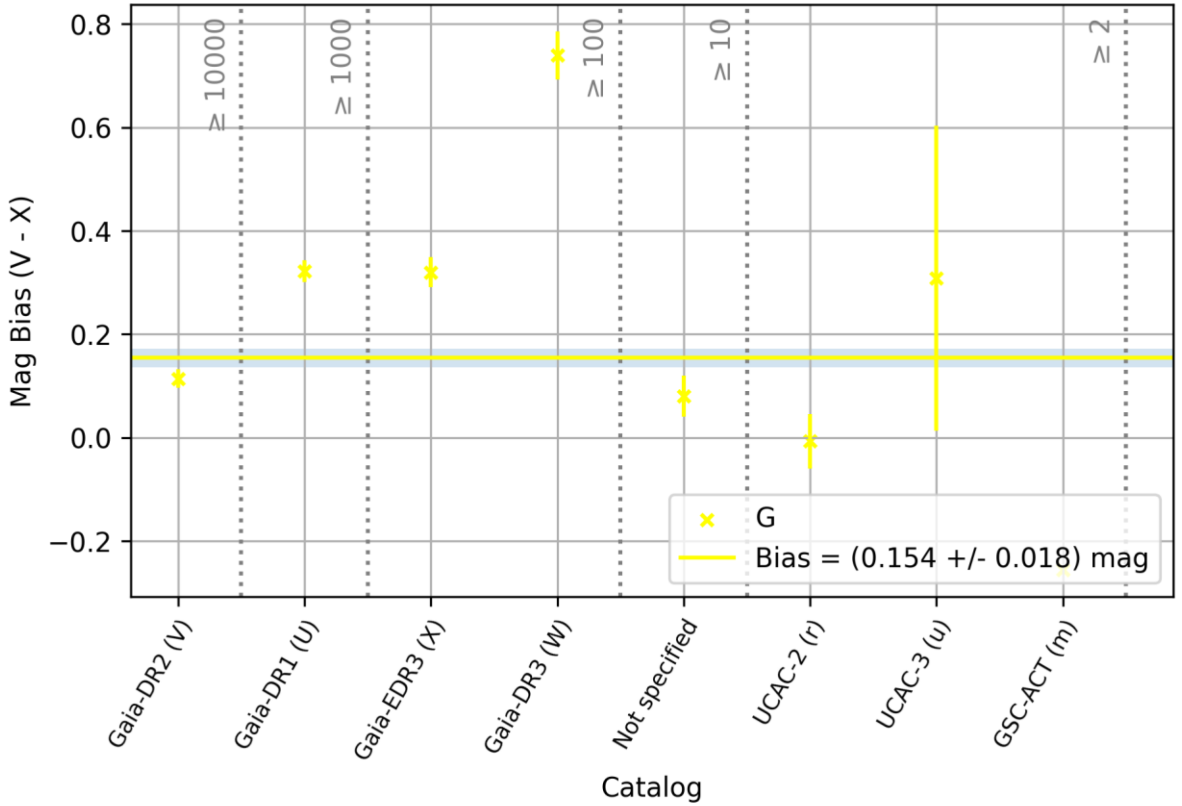
MPC correction

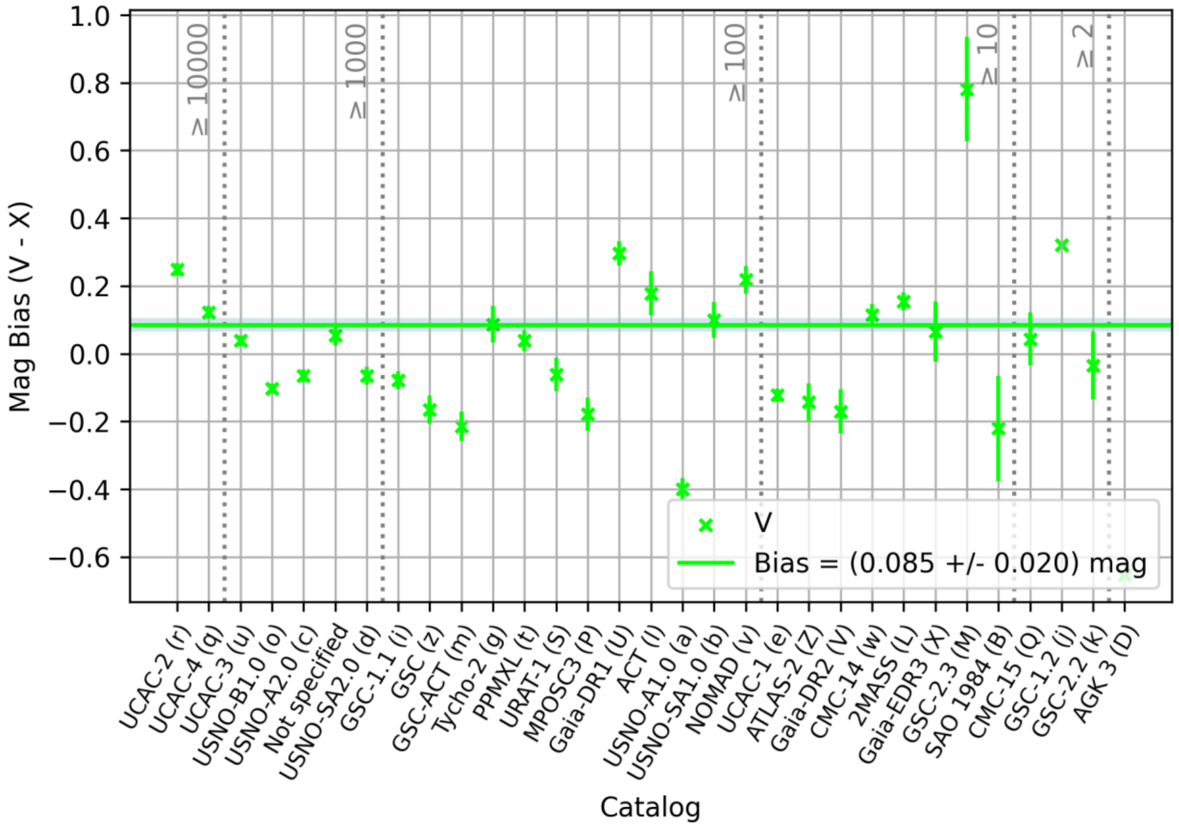
(Hoffmann et al., 2024)

Bias analysis system – Band-Catalog (BC)

- Comparison of different **catalog biases** within a color band (average band bias = central line)
  - Significant difference among the different photometric catalogs

(Hoffmann et al., 2024)





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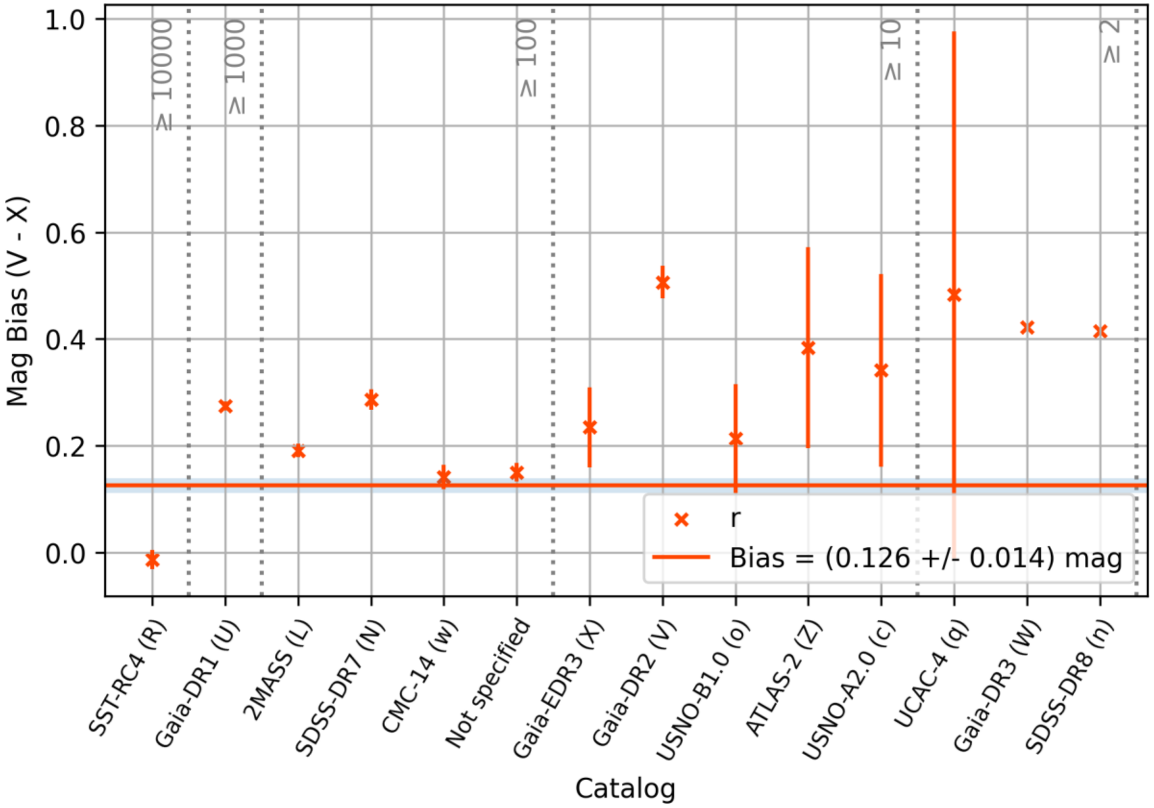
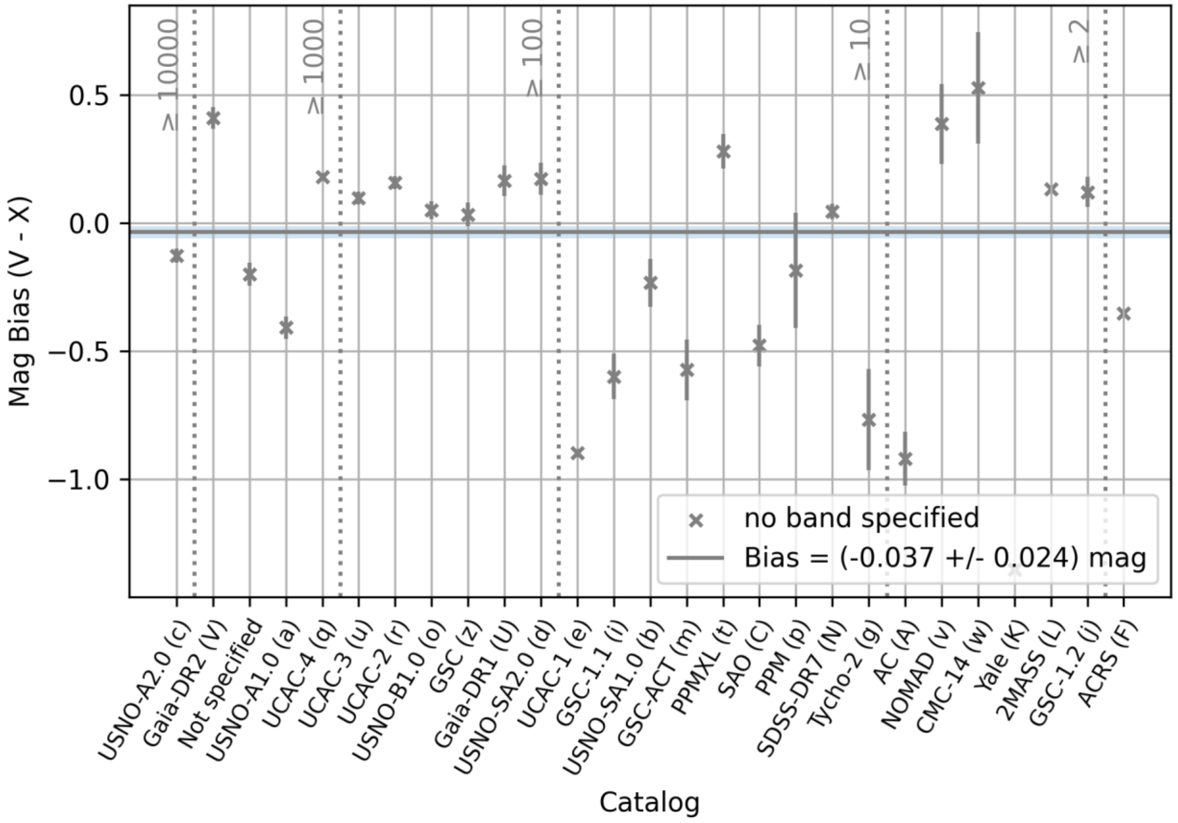


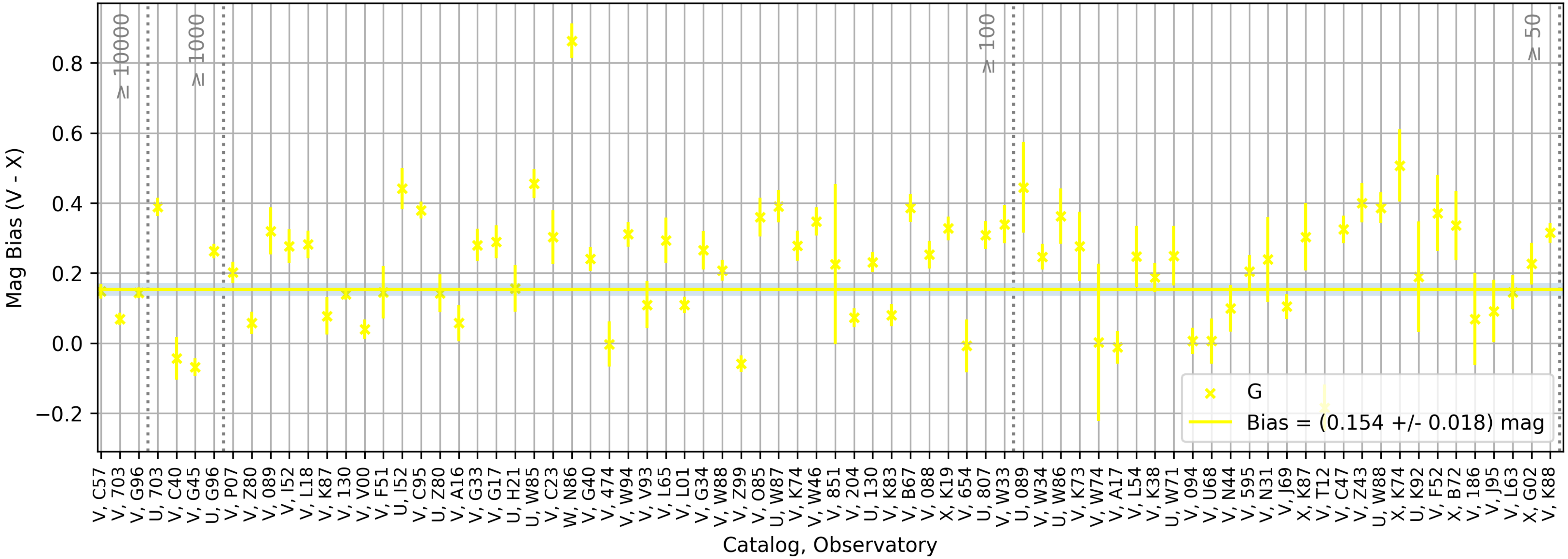


Results

Bias analysis system – Band-Catalog-Observatory (BCO)

- Comparison of different **observatory biases** within a band (average band bias = central line)
  - Significant difference among the different observatories

(Hoffmann et al., 2024)

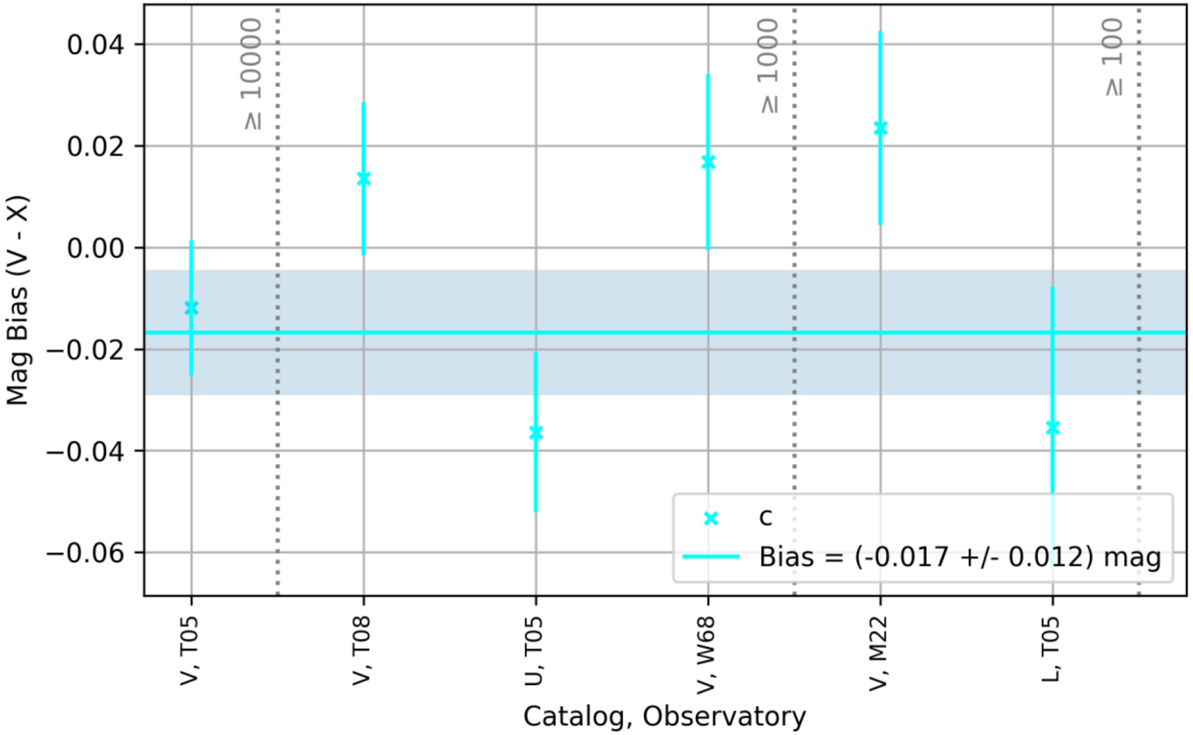


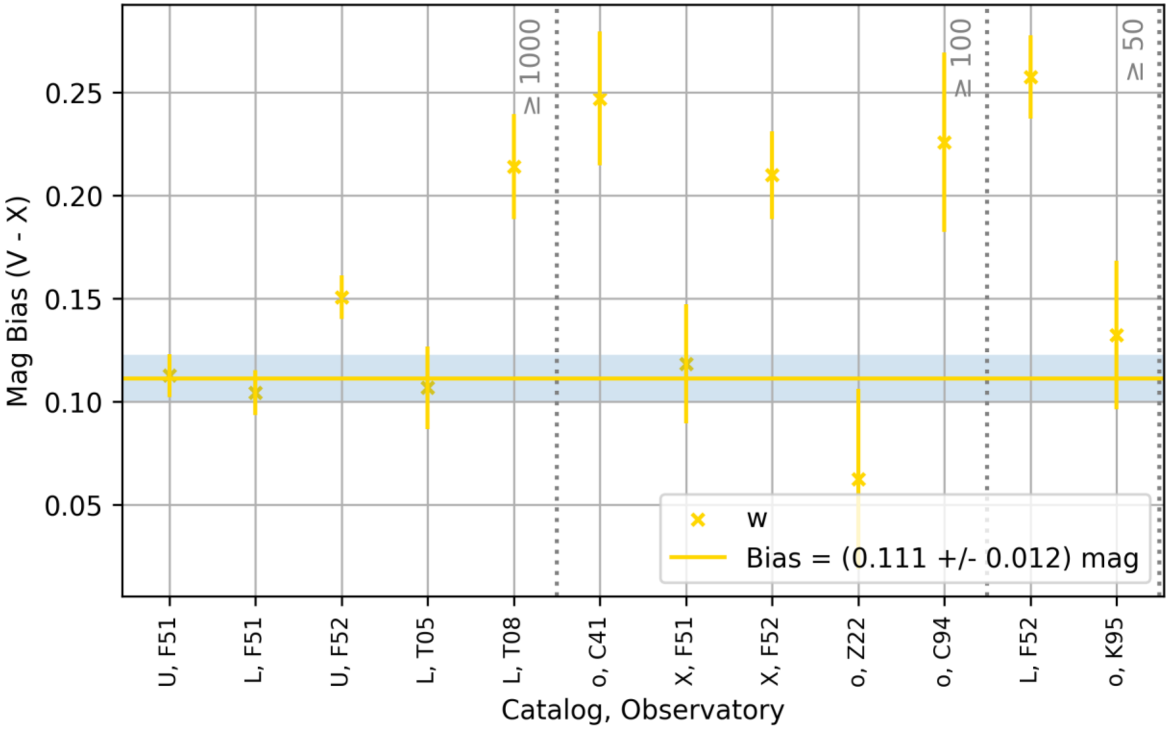
Results

Bias analysis system – Band-Catalog-Observatory (BCO)

- Comparison of different **observatory biases** within a band (average band bias = central line)
    - Most surveys are consistent with respect to each other, low deviations

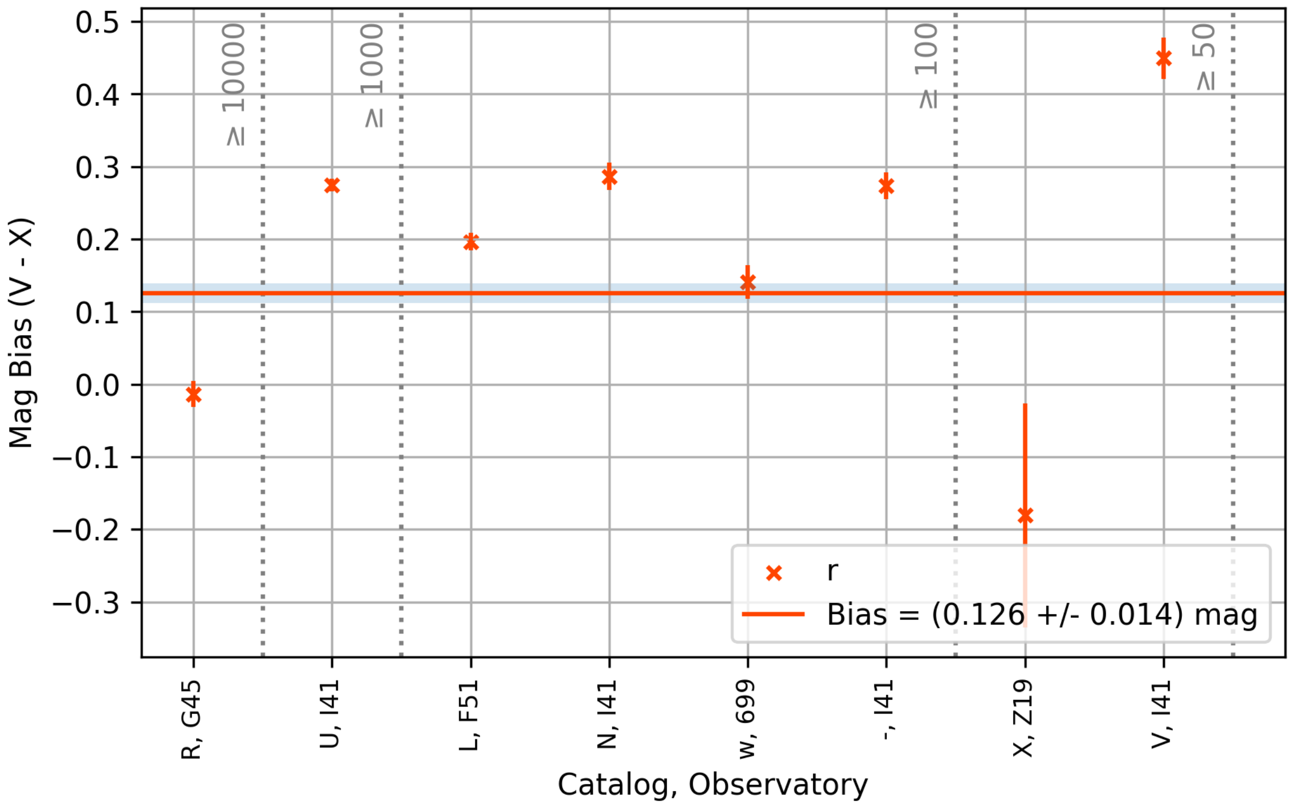
(Hoffmann et al., 2024)





Bias analysis system – Band-Catalog-Observatory (BCO)

- Comparison of different **observatory biases** within a band (average band bias = central line)
  - Effects of observatories already calibrating their photometry for band offsets



(Hoffmann et al., 2024)

Method

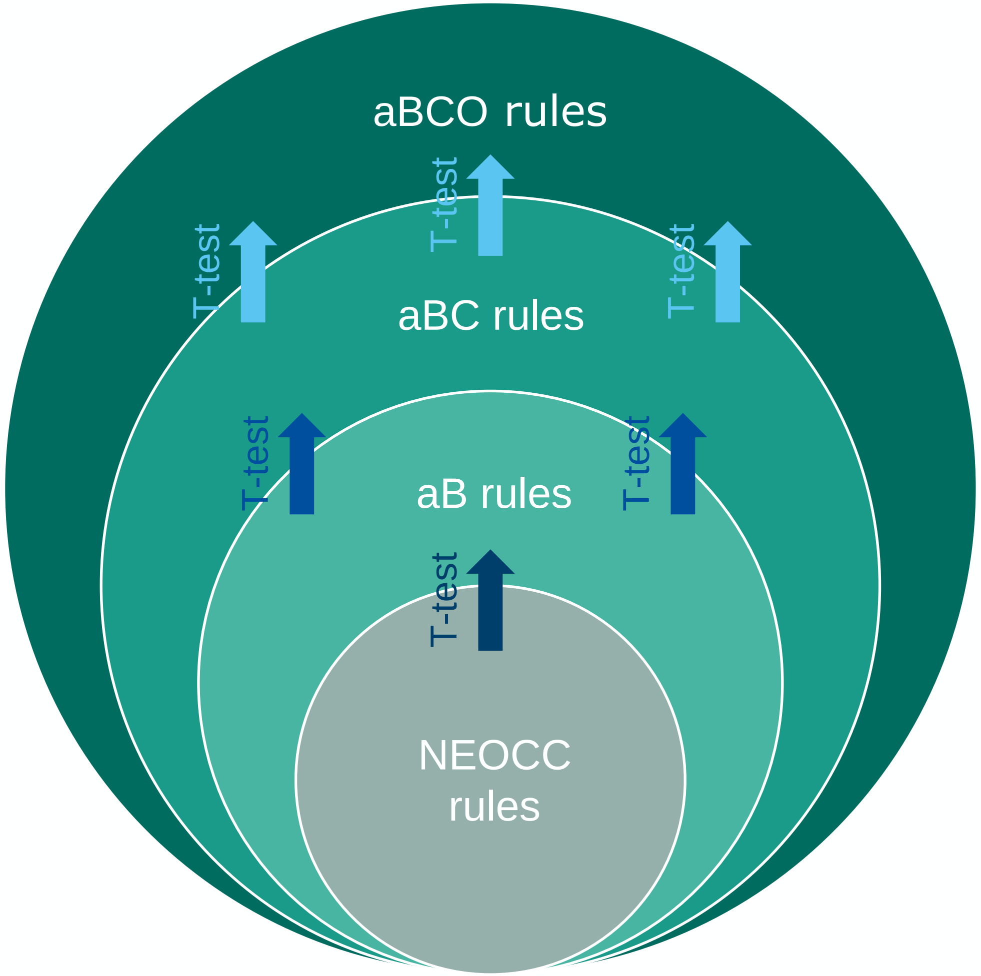
Design of correction algorithm

- **Basic idea:**
  - **BCO** results (band, catalog, observatory) if there is enough data for accurate correction
  - **BC** results (band, catalog) if there is enough data for basic correction
  - **B** results (band) if there is enough data for rough correction
  - Previous NEOCC correction if there are no results available

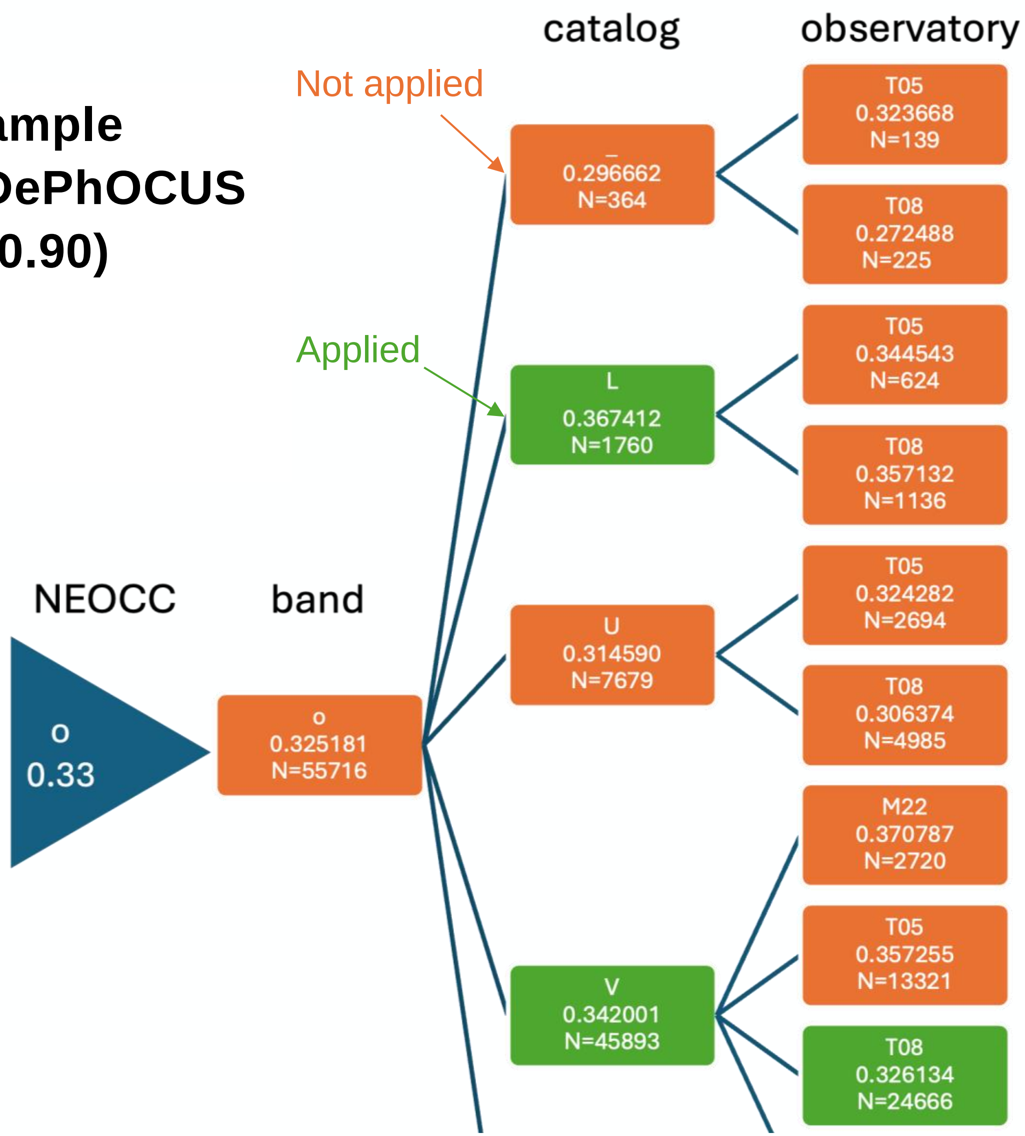
- **What is "enough"?**
  - This decision is done by a statistical methods to select the most relevant rules (t-test)
  - Iterative approach: Starting from NEOCC rules, expanding B, BC and then BCO corrections in cases when they are statistically significant (e.g., 90% p-level)

Method

Design of correction algorithm



Example in DePhOCUS (p=0.90)



Results

Correction system – Prediction of model

- **Idea**: Do calibration on one part of reference data, predict the other part and compare to measurements
  - 394 out of 468 asteroids (~84%) used for calibration
  - 74 out of 468 asteroids (~16%) used for validation of prediction

Correction	B	BC	BCO	RMS / mag	Change
None	0	0	0	0.4251	0.0%
MPC	24	0	0	0.4321	+ 4.0%
NEOCC	24	0	0	0.4244	- 0.4%
NEOCC[1]	*17	0	0	0.3768	- 27.6%
DePhOCUS					
$p = 0$	*20	159	2287	0.3720	- 30.3%
$p = 0.68$	*17	90	701	0.3621	- 36.0%
$p = 0.90$	*17	61	339	0.3613	- 36.4%
$p = 0.95$	*16	53	241	0.3622	- 35.9%
$p = 0.99$	*12	41	128	0.3691	- 31.8%

[1] Used by NEOCC since 2023-09-28 (including aB results)
* Additional to previous NEOCC correction

→

- **Debiasing** has meaningful effect, major influence by color band, but also catalog and observatory
- **Reduction** in the deviations by about **36%** compared to previous corrections
  - Assuming light curve effect/ photometric error boundary (0.25 mag)

(Hoffmann et al., 2024)

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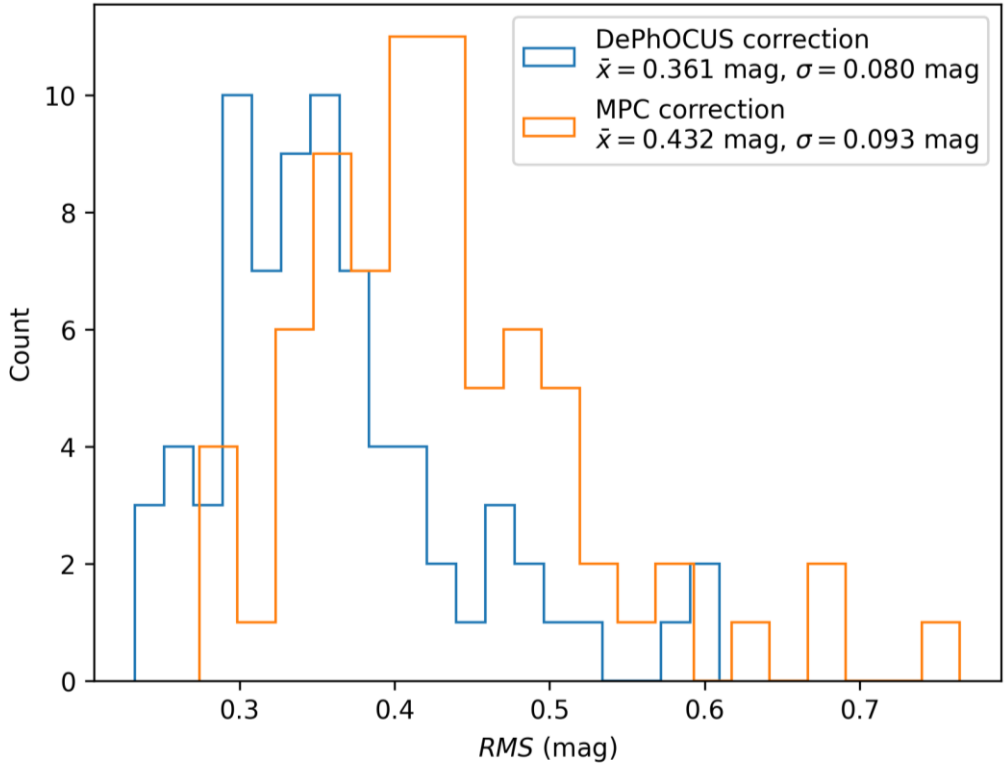
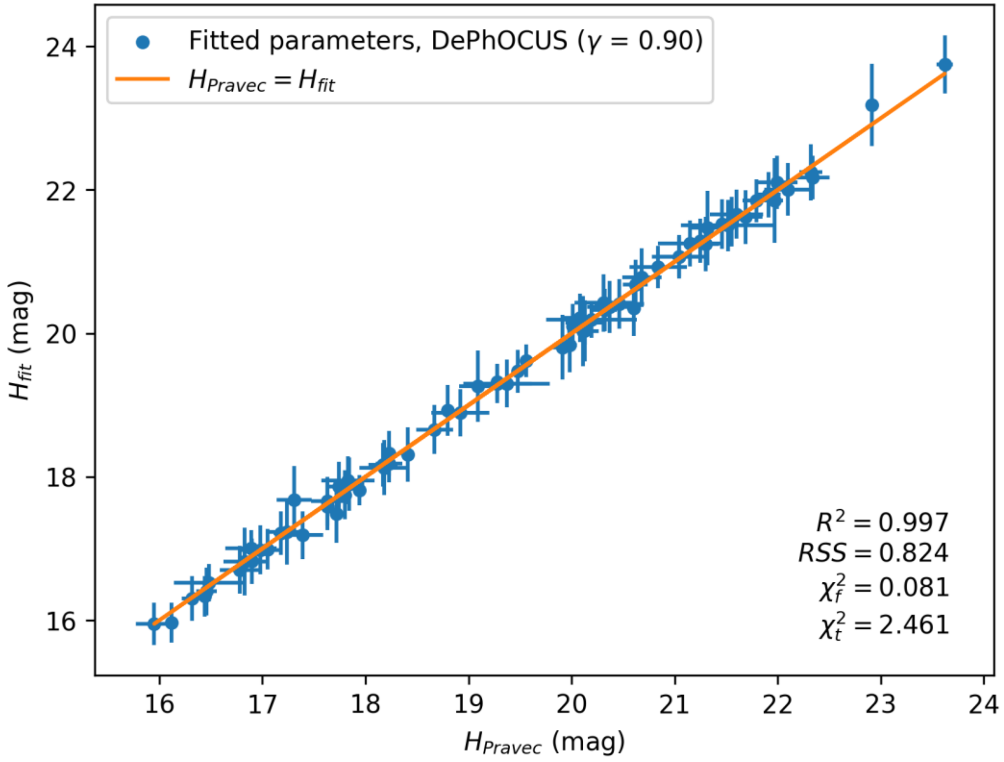




Discussion

Advanced bias analysis

- Additional advanced analysis to have a look at the influence of…
  - **Apparent magnitude** (SNR)
  - **Apparent motion** (effects of trailing)
  - **Absolute magnitude** (size of asteroid)
  - **Galactic latitude** (density of surrounding stars)
  - **Astrometric residuals** (measuring errors)
  - **Evolution of time** (long-term effects)

  … on the bias and accuracy of the measurements for large stations

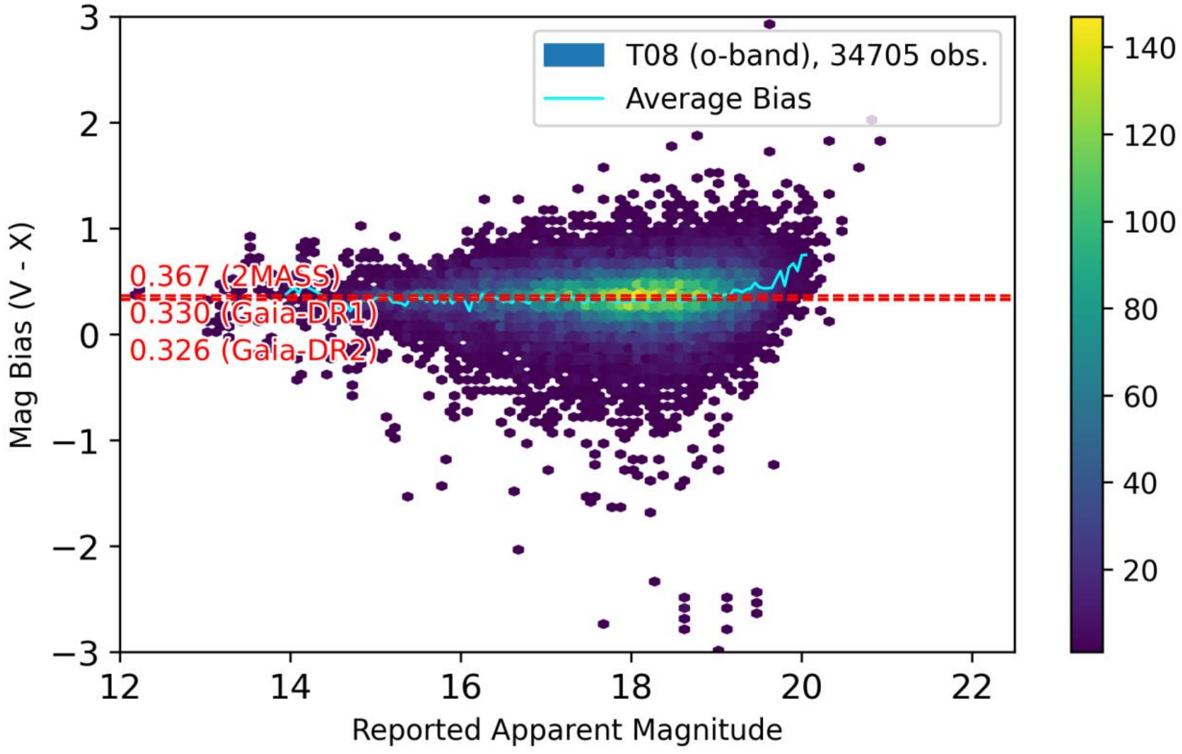
- These might be important to understand possible issues/improvements of the new method

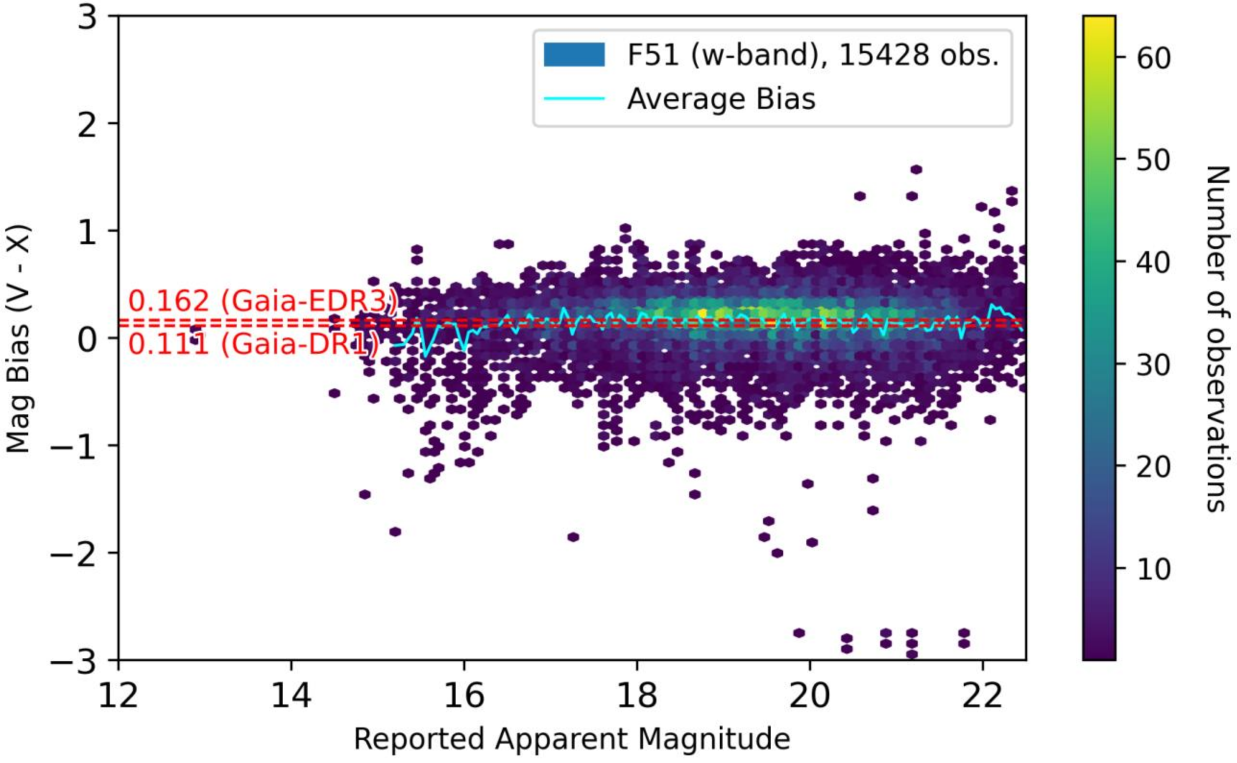
Discussion

Advanced bias analysis

- Effect of the **apparent magnitude** on the bias of large stations; changes near the detection limit of observatory?
  - Creating density plots for each obscode-color combination

(Hoffmann et al., 2024)



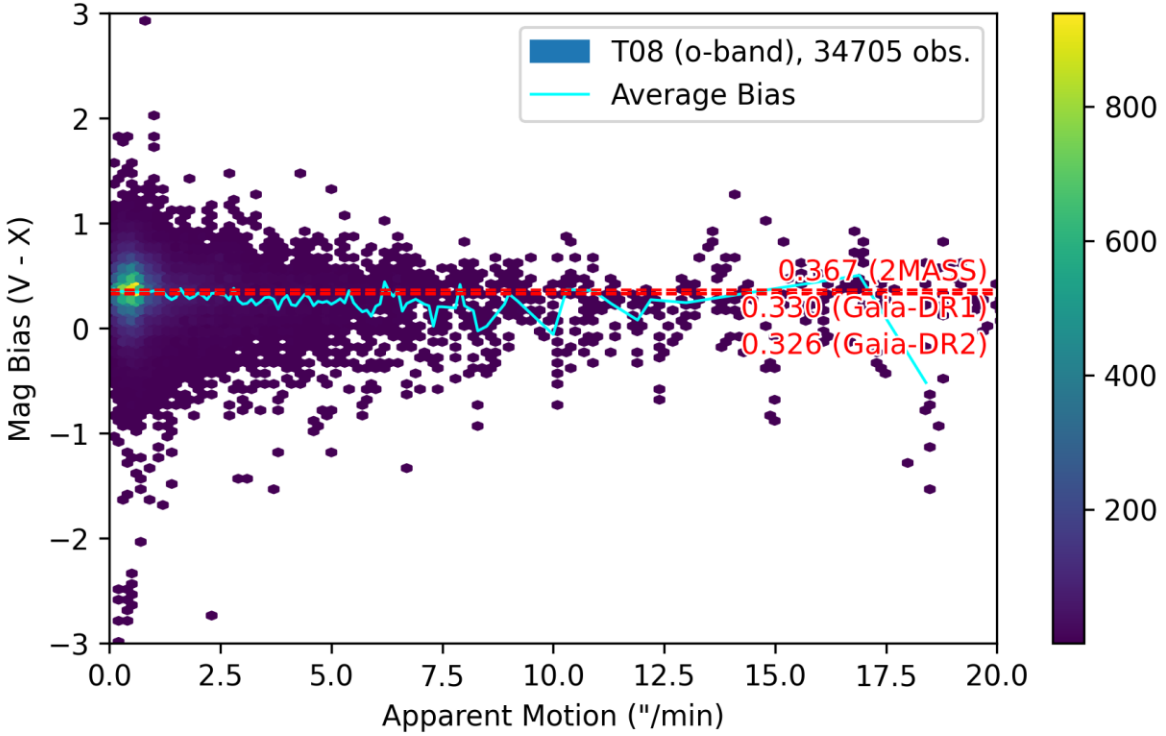


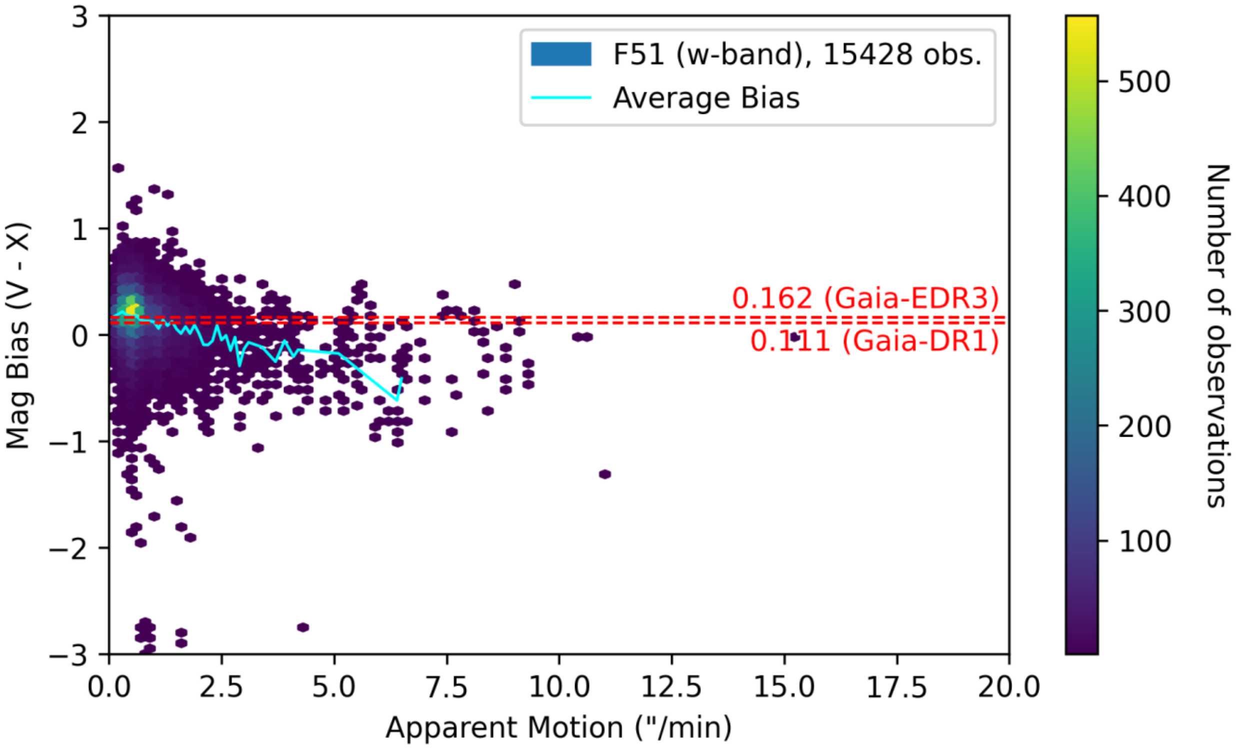
Discussion

Advanced bias analysis

- Effect of the **apparent motion** as a measure for trailingon the bias and accuracy for large stations
    - Creating density plots for each obscode-color combination

(Hoffmann et al., 2024)



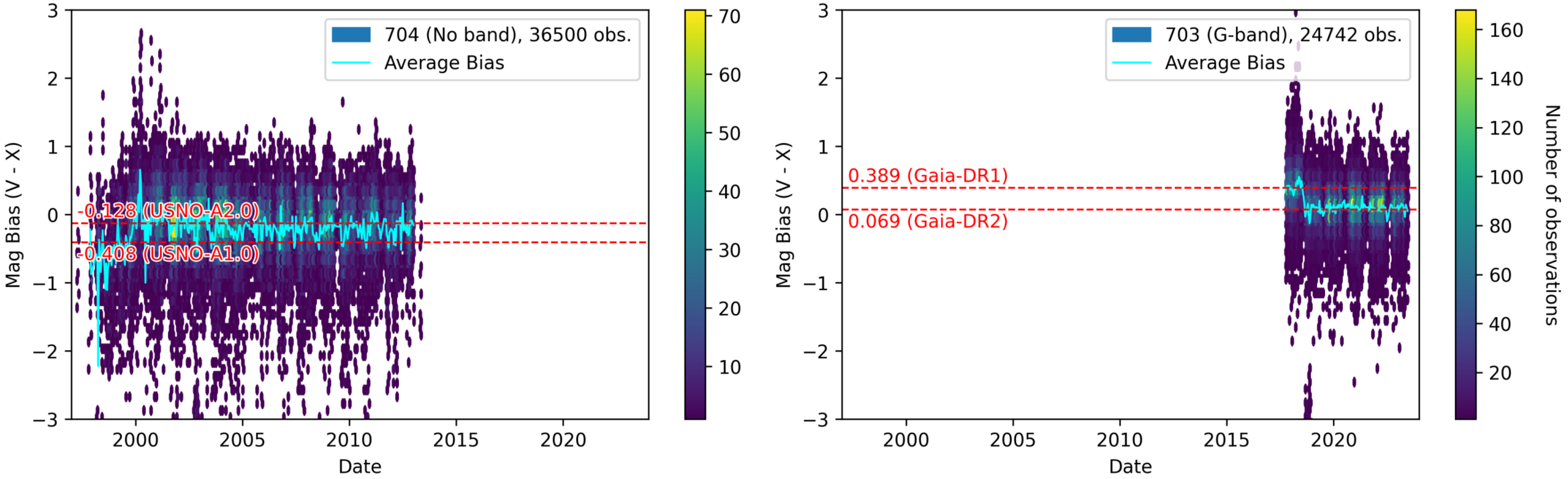


Discussion

Advanced bias analysis

- Effect of the **time of observation** on the bias of large stations to see if something changed over time
  - Creating density plots for each obscode-color combination

(Hoffmann et al., 2024)



Discussion

Future works and improvements

- Using larger dataset about physical properties / model parameters
- Improvement of G parameter estimation
- Including more recent models of absolute magnitude (e.g., Muinonen (2010), Penttilä (2016), Carry et al. (2024))
    - HG_1G_2, HG_{12}^* and sHG_1G_2
    - Need for a (large) photometric reference database for these models
- Weighting the observations by the expected accuracy
- Making use of ADES format, using uncertainties in weighting
- Long-term investigation, more observations (and possible changes over time)
- …

Discussion

Community

- The presented analysis opens now new questions on the photometric observations of asteroids:

  A. How should observers provide their photometry? How can specific pre-calibrations be indicated?

  B. Should it be possible to submit dedicated photometry to the MPC?

  C. Should MPC/JPL/NEOCC apply corrections for (past) measurements?

  D. Is the V-band a suitable reference band for optical observations (anymore)? Alternative?

  E. How can the confusion between ‘band’ and ‘filter’ be minimized?

  F. Should there be campaigns focusing on the photometry of NEOs (comparable to timing-campaign)?

  G. …

Summary

- Photometric observations of asteroids have **systematic biases** for band and catalog.
- Observations from different observatories **varies** strongly in **accuracy** and **contain offsets**.
- Statistically analysing observations allows the derivation of **specific corrections**.
- Applying multi-parameter corrections results in a significant **reduction of errors**.
- New debiasing leads to **better** photometric description and **asteroid size estimation**.
- More data and a **long-term investigation** is needed, other **models** should be considered, as well.
- Discussions on **standardization** of photometry calibrations in the **community** should be made.

References

Main description of this work

- Hoffmann, Tobias et al. (2024): Debiasing astro-photometric observations with corrections using statistics (DePhOCUS). Icarus 116366, DOI: [10.1016/j.icarus.2024.116366](https://doi.org/10.1016/j.icarus.2024.116366)

Additional

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Thank you for listening!

Produced by

Tobias Hoffmann
Young Graduate Trainee

Science Missions Support Section (OPS-GFS)

Flight Dynamics Division

Directorate of Operations

European Space Agency