Ground Based Optical Tracking of the Gaia Satellite (GBOT)

Martin Altmann
Zentrum für Astronomie (Astr. Recheninstitut)
Heidelberg, Germany

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The VST in the era of large Surveys

Capodimonte, Napoli, Italia

esa

European Space Agency

gaia

Gaia DPAC

Outline

1. The GBOT story
2. The GBOT Asteroid programme
3. The GBOT Asteroid programme as a use-case for the VST in the era of large surveys

Chapter 1:
The GBOT story

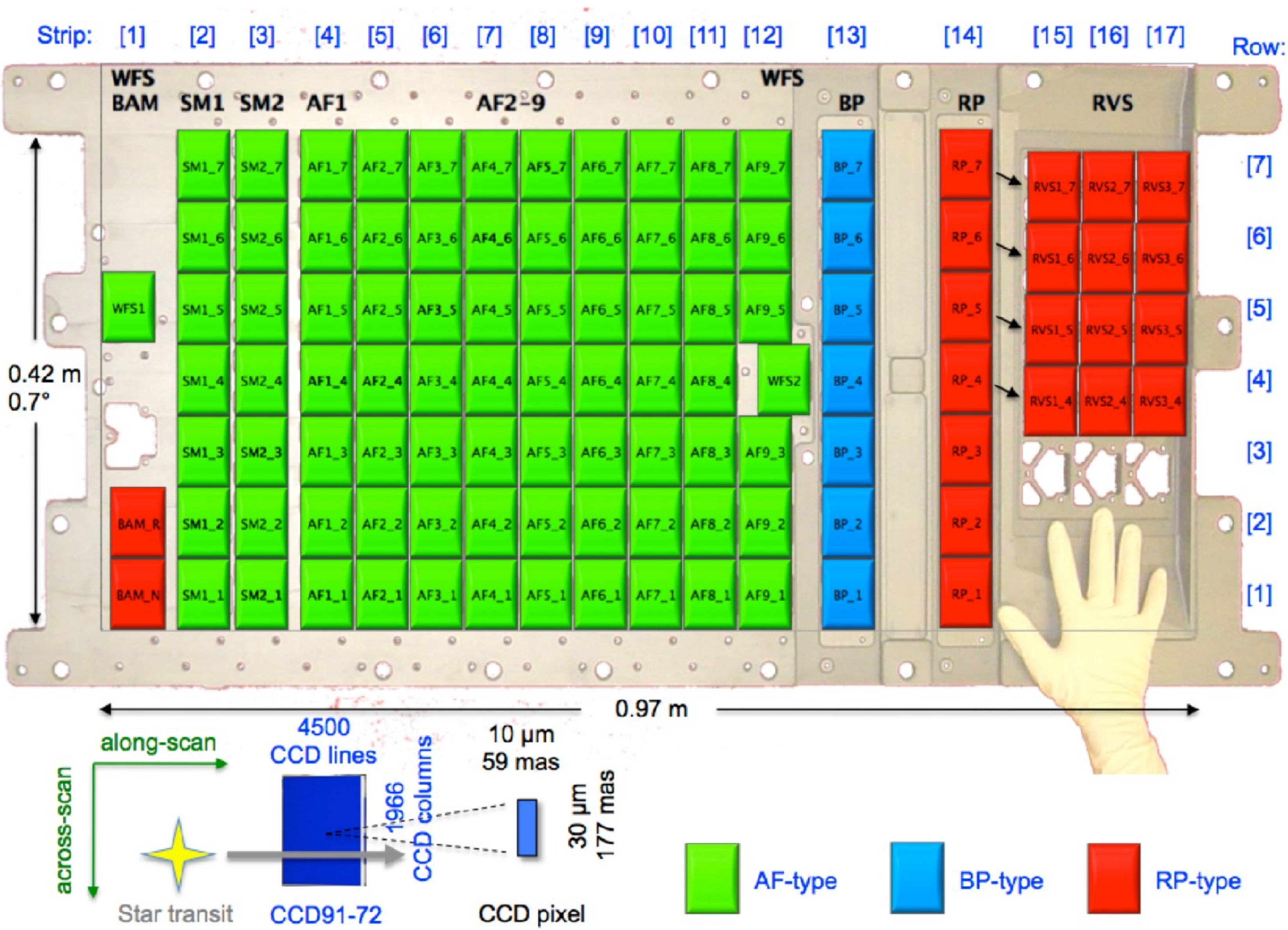
Some words about Gaia

- Gaia is the most ambitious space astrometry mission thus far
- Micro arcsecond astrometry of 1+ billion stars (DR2: 1.6 billion), but also QSO, SSO, etc.
- Is revolutionising our understanding of our Galaxy and thus of galaxies in general
- contributes to many other fields: fundamental physics, the Solar system, stars, etc.

Some words about Gaia

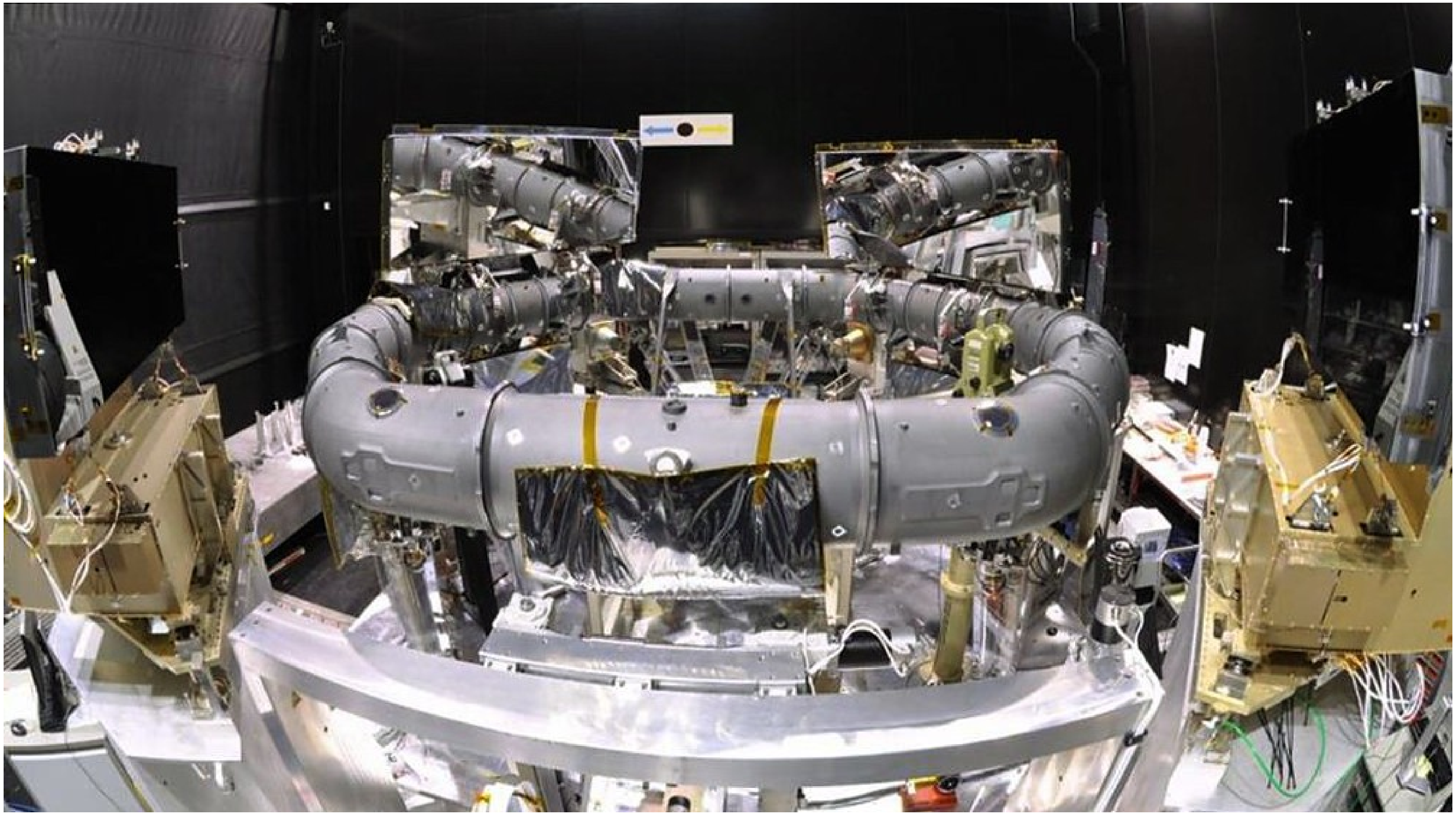
- Gaia measures astrometry, blue and red spectrospectroscopy (low-res), and hi-resolution spectroscopy for radial velocities, physical pars, abundances
  - 1st data release: Sept. 14, 2016, 1.143 billion objects, 2 million with proper motions and parallaxes (TGAS)
  - 2nd data release (DR2), April 25, 2018, 1.6+ billion stars, 1.3+ with colours and full 5 par astrometry, astrophysical parameters, radial velocities for subsets, 300,000 variable stars, minor planets, etc.
  - Nominal measuring phase: 2014 – mid 2019, 1st extention period approved (- end 2020), on board resources may last until 2024.

Some words about Gaia



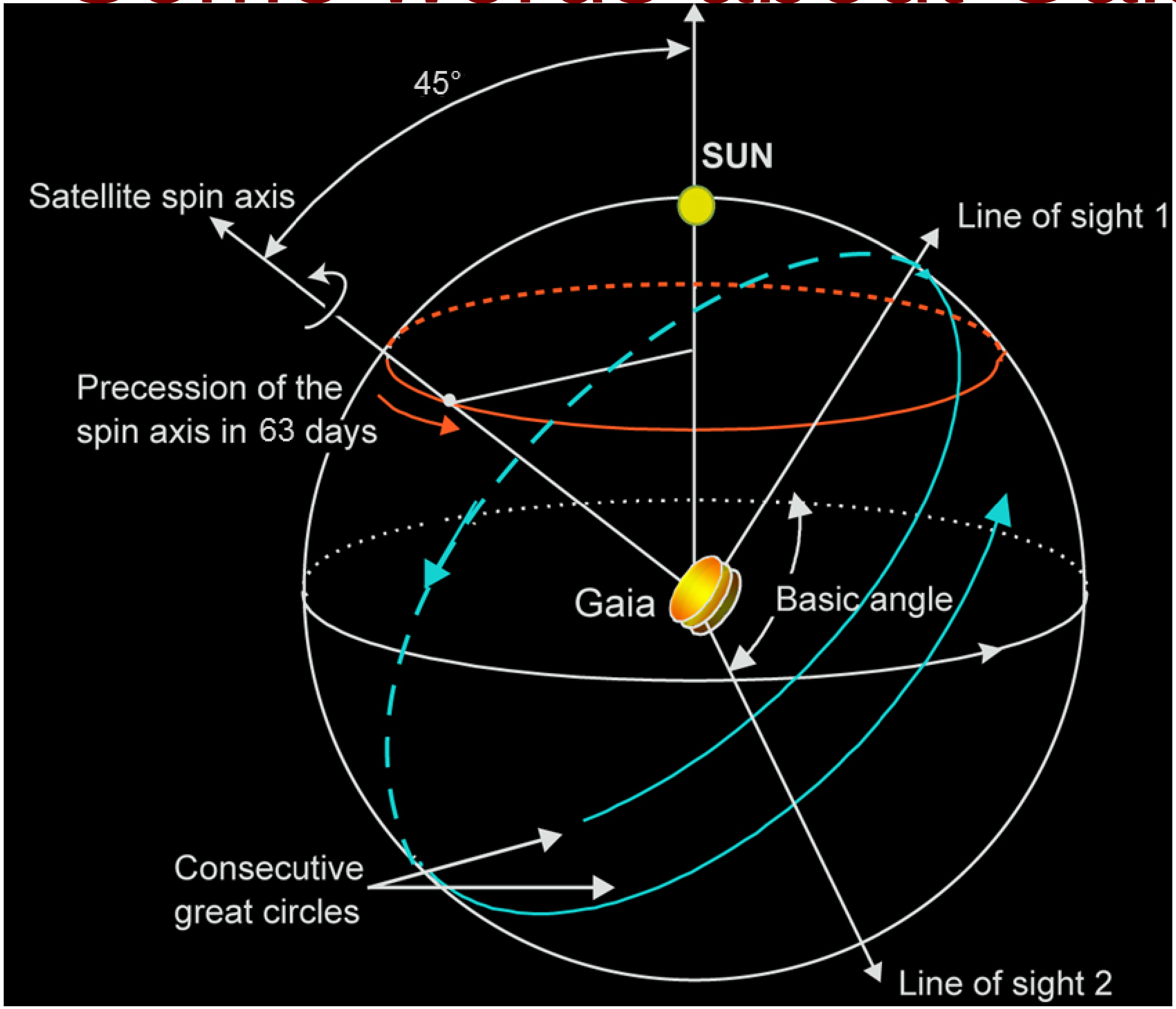
The focal plane

Some words about Gaia



Gaia's optical assembly

Some words about Gaia



Gaia's NSL scan law

GBOT – what is it, why do we need it?

Micro arcsecond astrometry accuracy goals not obtainable for all objects using conventional ranging methods.

- For the baseline for SSO parallaxes and to combat the effect of aberration for the most precisely measured objects, further steps must be taken
  - GBOT (***G***round ***B***ased ***O***ptical ***T***racking) – hi precision&accuracy astrometric tracking of the satellite from earthbound telescopes
  - DeltaDOR (Delta Differential One-way Ranging):
    - Highly precise, but:
      - Only 3 antennae available worldwide (Cebreros (ESP), Malague (ARG), New Norcia (AUS) , at least 2 baselines required by DDOR
      - During DDOR no data download
      - Other missions also need resources, especially in “Mars years”, i.e. 2016, 2018,... , right now the competition for antennae is fierce

So GBOT is born ...

GBOT (Ground based optical tracking)

- Worldwide small network of 1-2 m telescopes
- Daily (24 hrs) observations
- Requirements of state vector knowledge:
  - 150 m in position
  - 2.5 mm/sec velocity
- Translating to:
  - 21 mas or 30 mas/d
- GBOT’s task:
- Obtain 20 mas astrometry on daily basis

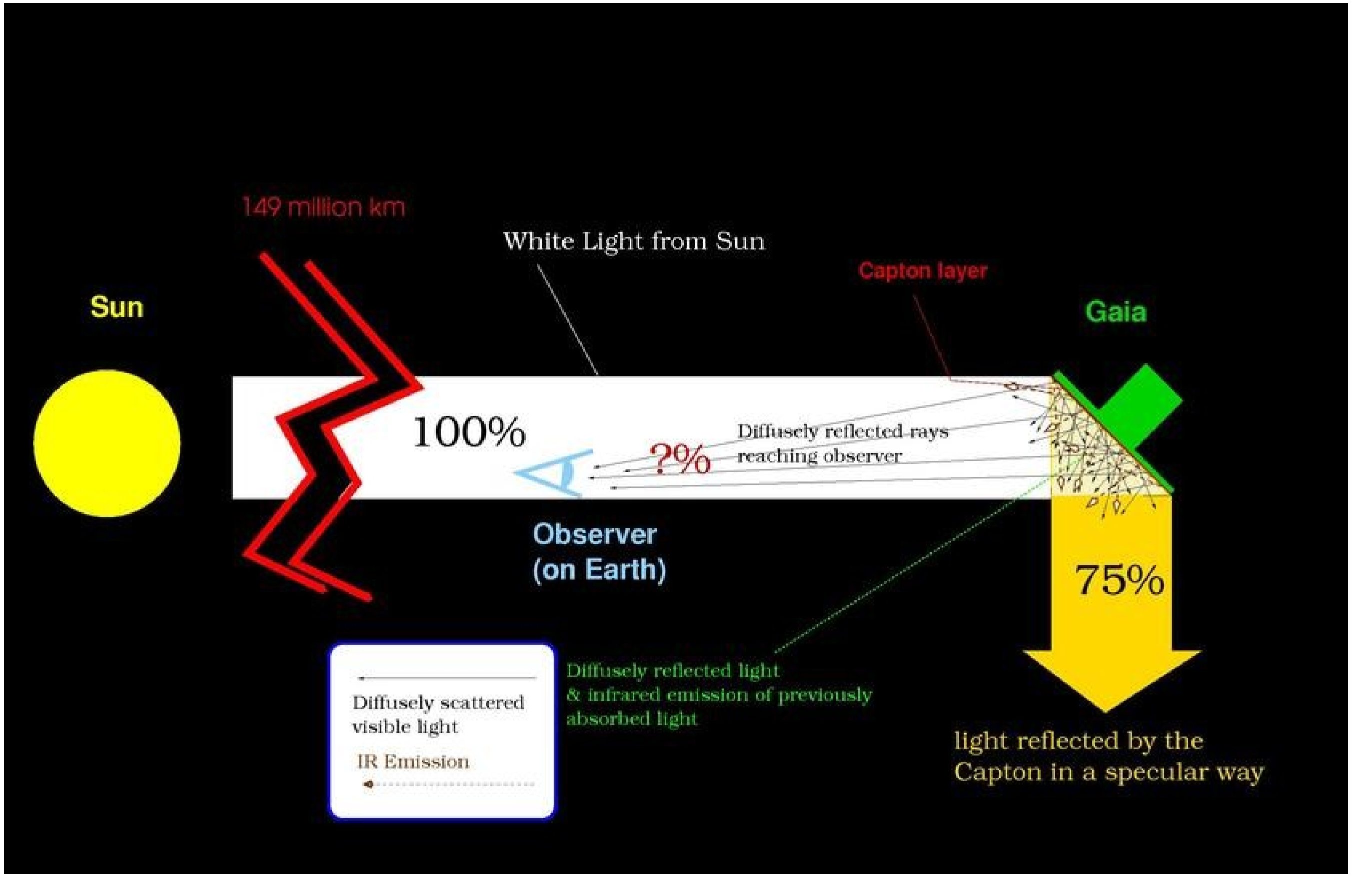
The GBOT team

- Leader (Work-package manager) and "GBOT office": Martin Altmann (Heidelberg)
  - Outward communication and representation of GBOT within DPAC
  - Planning
  - Coordination
  - Proposals and phase 2
- Paris GBOT data centre: Sebastien Bouquillon, Francois Taris, Teddy Carlucci, Christophe Barache, Martin Altmann (from remote)
  - Computer and database infrastructure
  - Software development
  - Analyses
  - Daily operations
- Observatories: Tim Lister (LCO), Jon Marchant (LT), ESO (Monika Petr-Gotzens)
- Others: Ricky Smart, Alex Andrei, Rene Mendez, …
- Gaia Project Scientist (for ESA-ESO collaboration): Timo Prusti

Gaia’s launch & GBOT’s woes

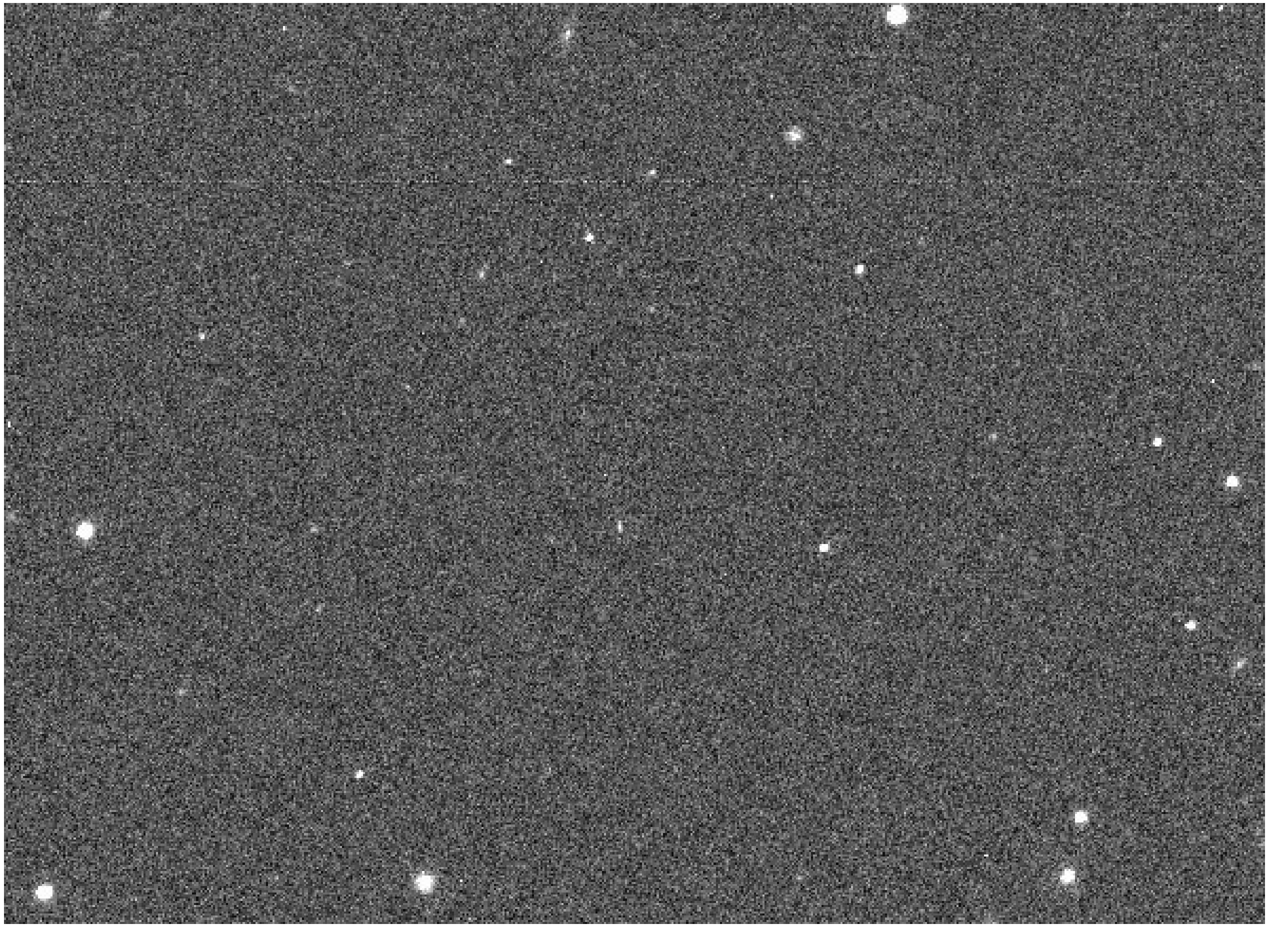
- 19.12.2013: Gaia launched
- Two days later amateur observations of Gaia’s brightness started coming in, leading to an estimated final brightness of R~21 mag instead of the anticipated 18!!!!
- GBOT reassessment programme
  - GBOT is feasible with 2 m class telescopes
  - Much reduced arsenal (1 m class telescopes were out of the game)
  - VST (80%) and Liverpool (20%) telescope are main instruments, FTN/S backup
  - GBOT team had to really delve into the basics of stellar (point source imaging) and signal yield (Cramer Rao Lower Bound), see Bouquillon et al., 2017, A&A, 606, 27

GBOT's woes



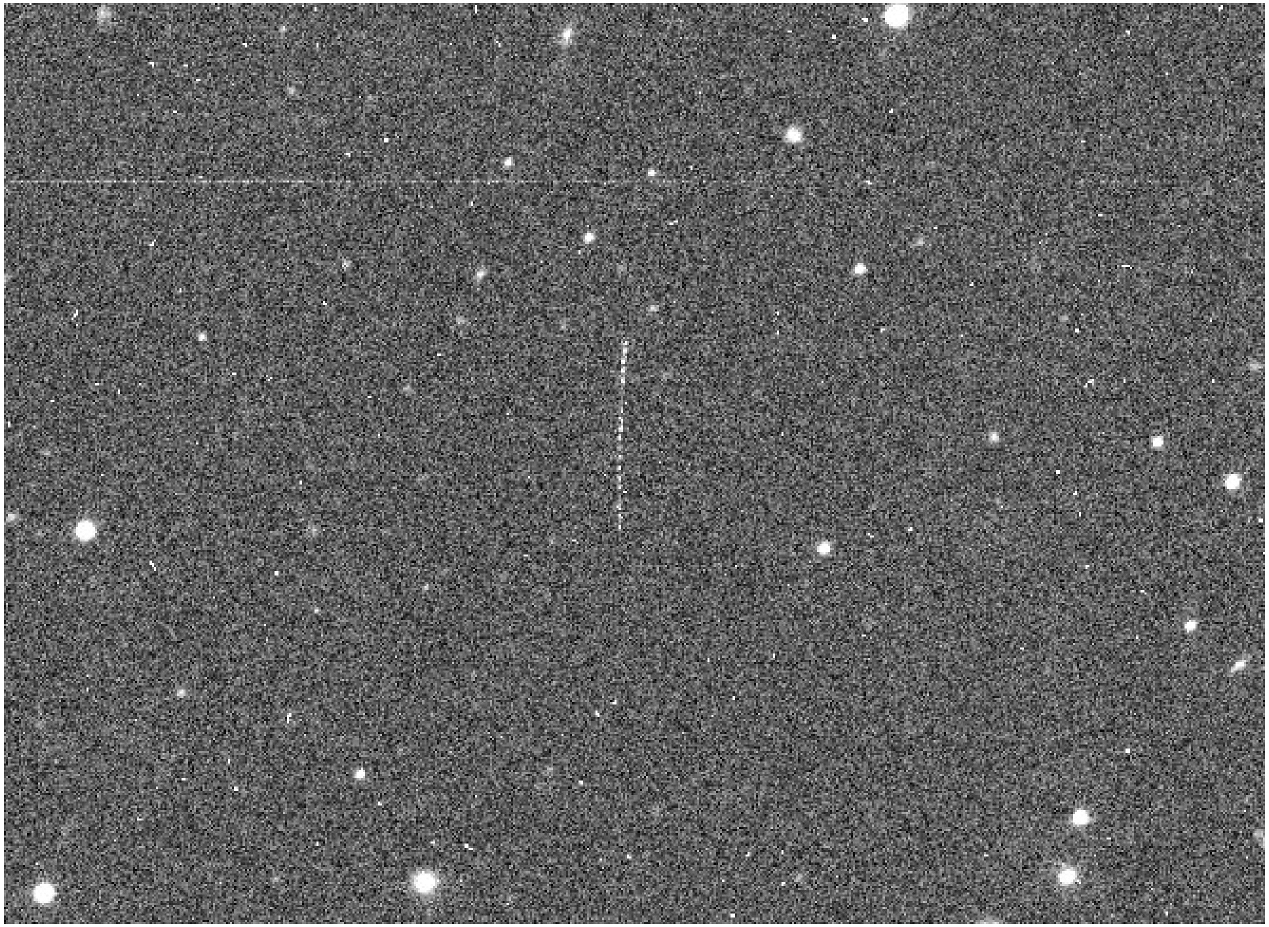
149 million km
White Light from Sun
Capton layer
Sun
Gaia
100%
?%
Diffusely reflected rays
reaching observer
Observer
(on Earth)
75%
Diffusely scattered
visible light
IR Emission
Diffusely reflected light
& infrared emission of previously
absorbed light
light reflected by the
Capton in a specular way

Gaia, as GBOT sees it



Gaia observed with the Liverpool telescope, on Sep. 26, 2016

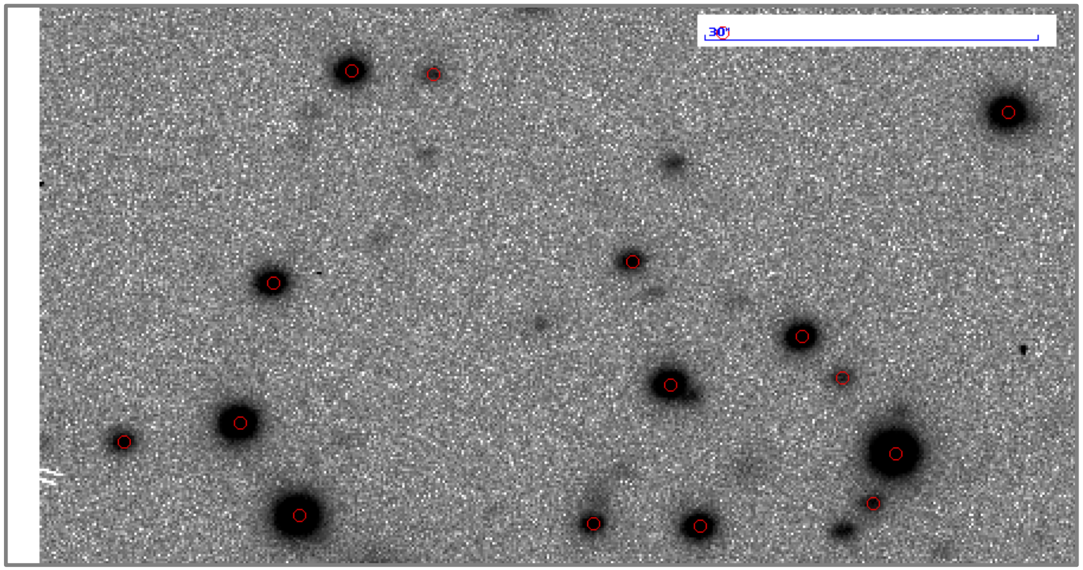
Gaia, as GBOT sees it

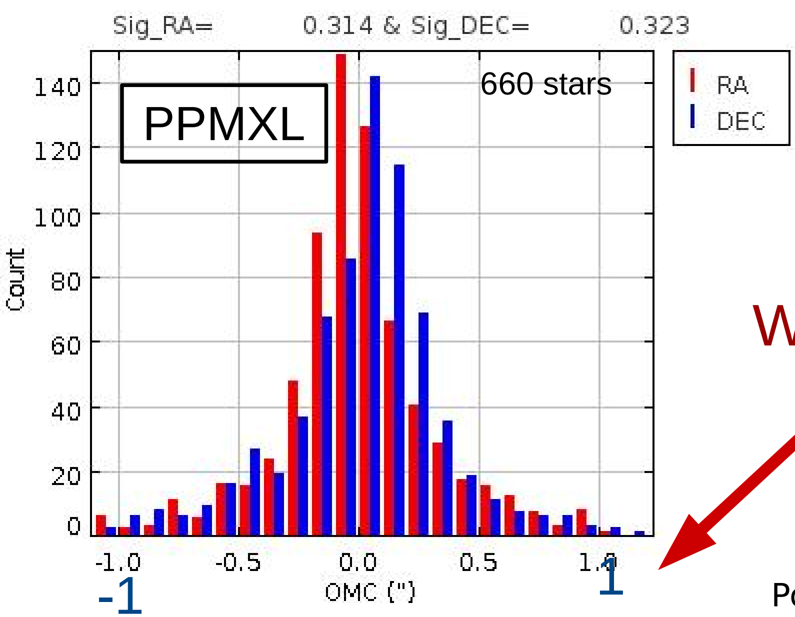


Gaia observed with the Liverpool telescope, on Sep. 26, 2016

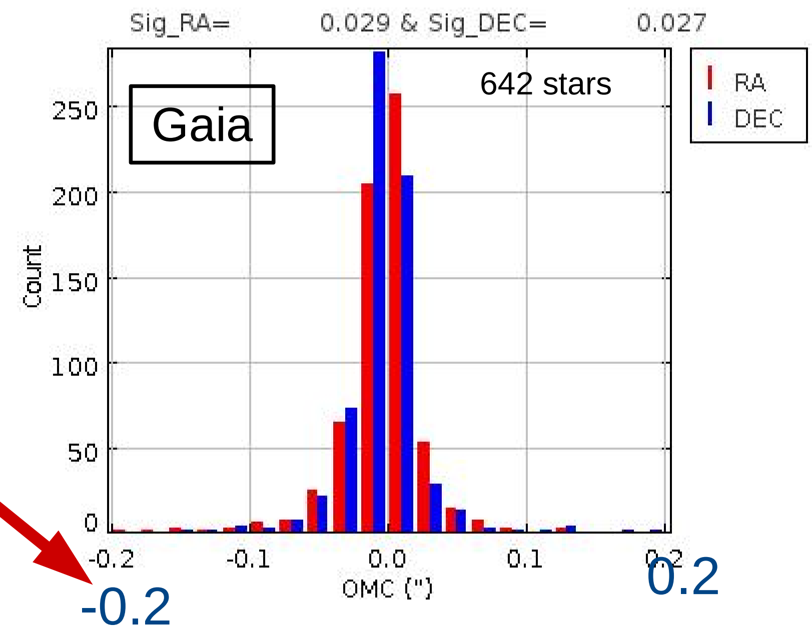
PPMXL vs. DR1

VST Image *(CCD n° 12) 22/07/2014*



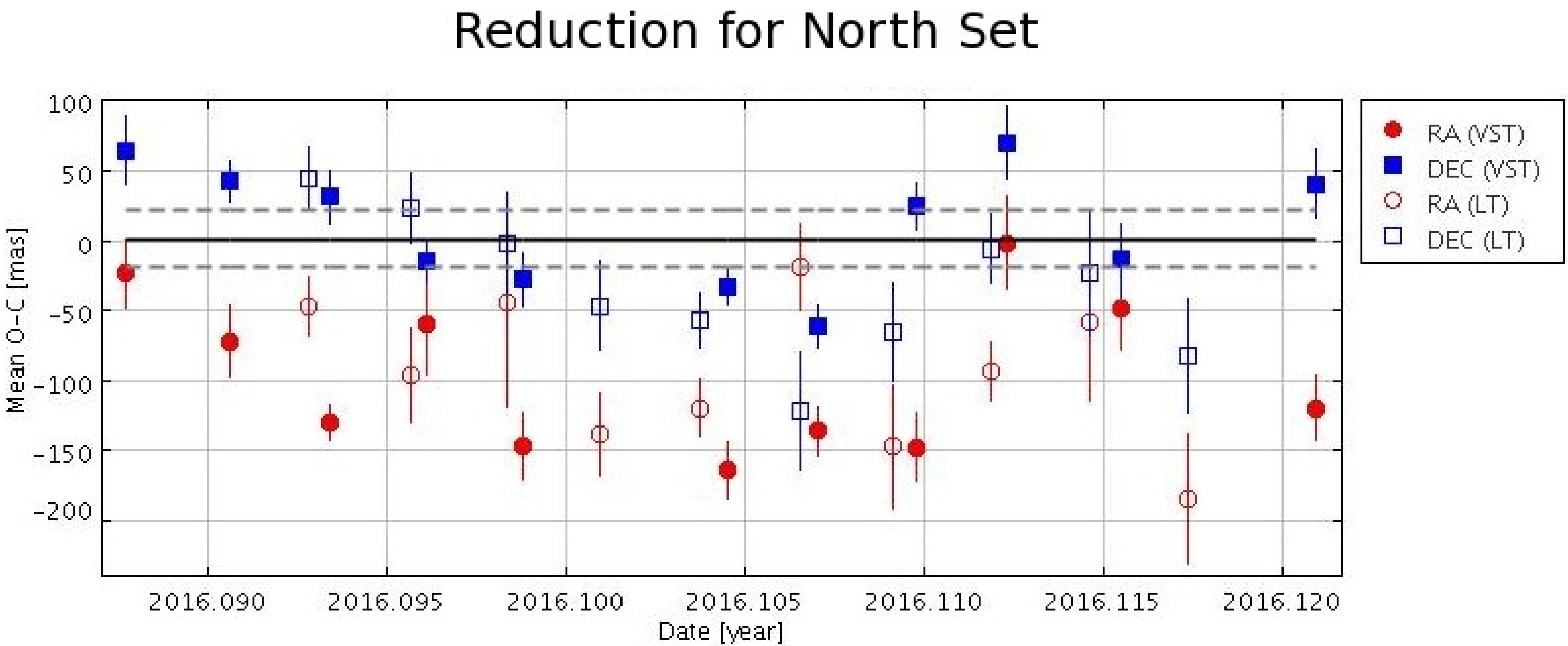


Watch the scale!!!



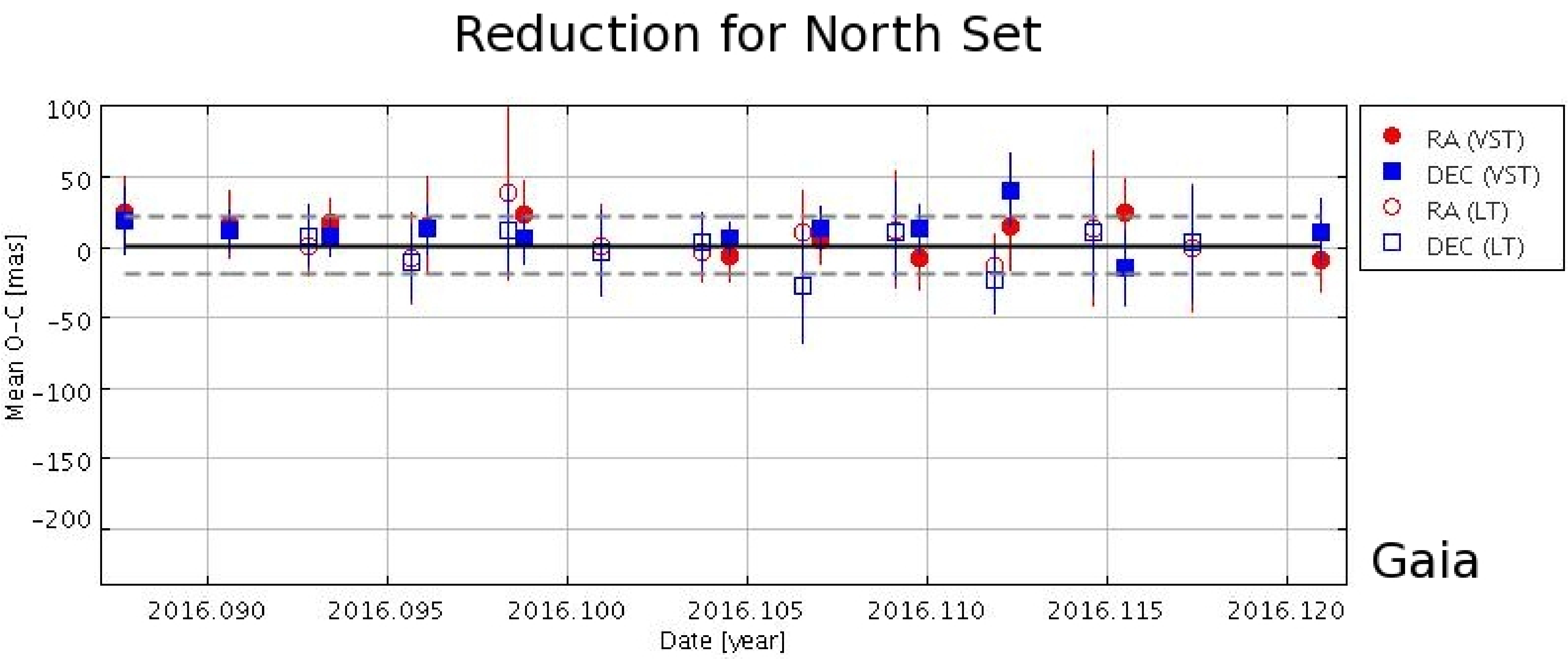
Polynomial of first degree

Before DR1



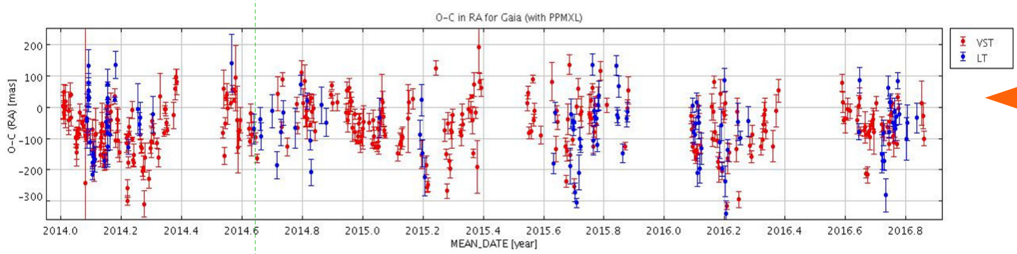
Typical 17 day stretch of daily data reduced with conventional catalogues

After DR1



Typical 17 day stretch of daily data reduced with Gaia DR1

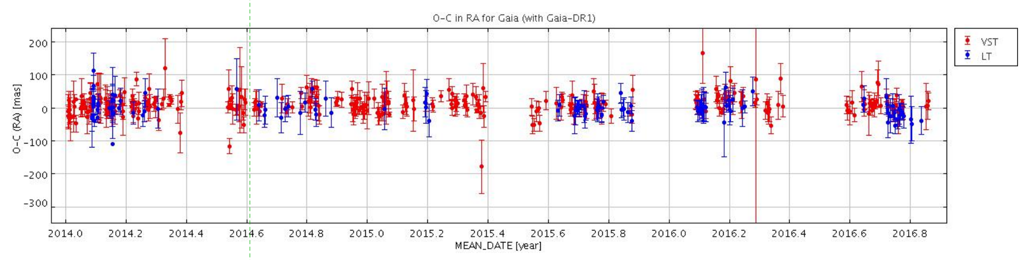
The whole dataset (2014 - 2016)



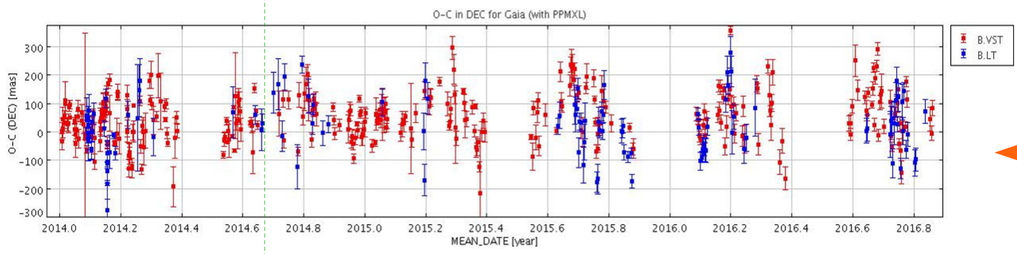
R.A.: PPMXL

R.A.: Gaia DR1

Commissioning phase

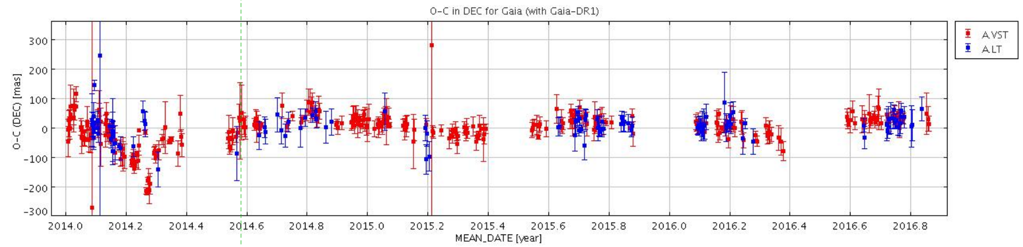


Commissioning phase



DEC: PPMXL

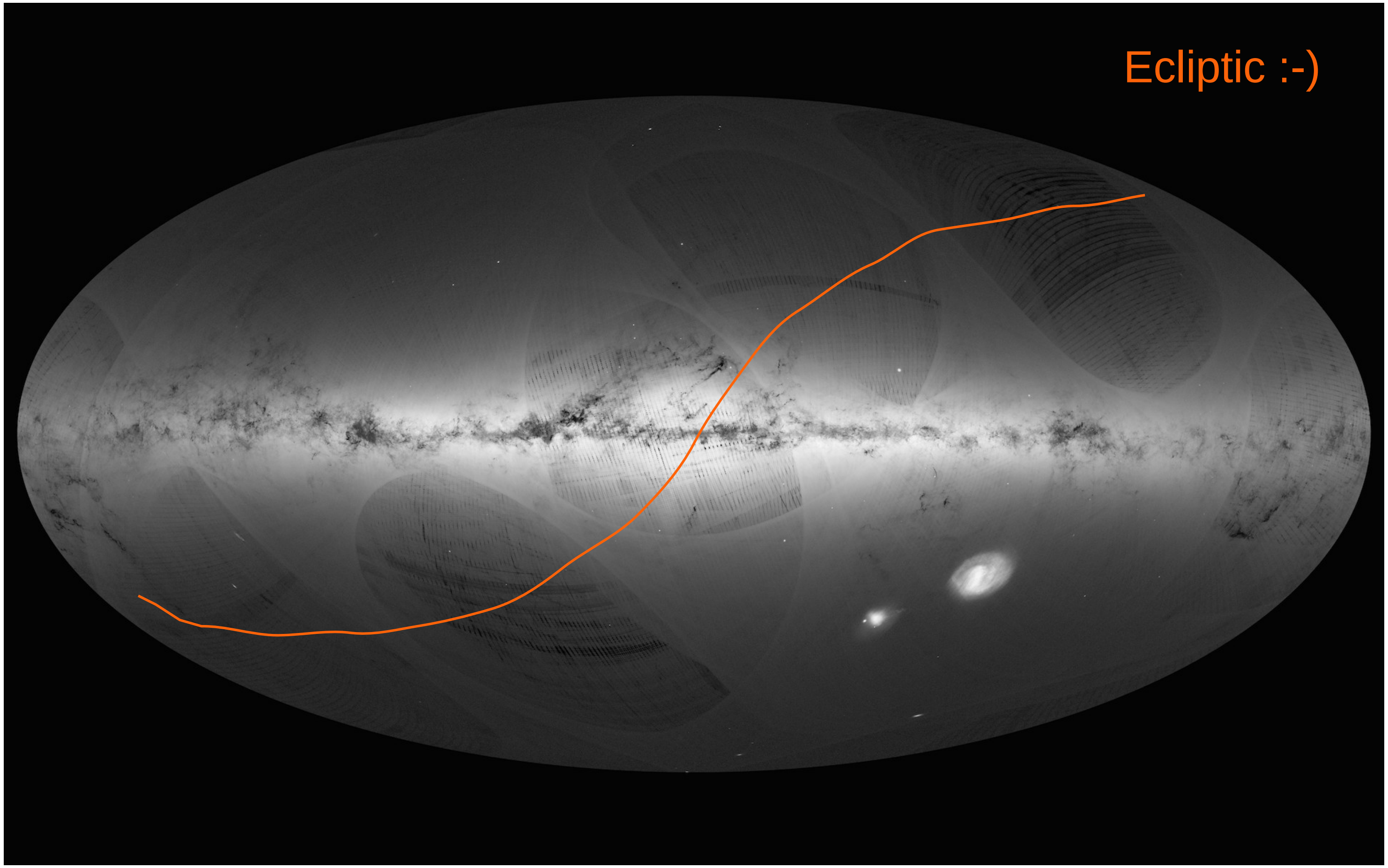
DEC: Gaia DR1



1st Resume

- Moving from PPMXL (e.g.) to Gaia DR1
  → enormous improvement on day to day residuals
- Secondary effects become visible:
  - DR1 has no proper motions → local net proper motion (caused by Galactic rotation) will cause time dependent effect on measurements
  - VST shutter equation overlooked → 0.4 sec offset in observing times
    - fixed
  - DR/**DCR** will also show itself to a lesser degrees
  - Tertiary effects might be: telescope location, timing, others (Note: the GBOT team thinks that these are rather unlikely to play a significant role)

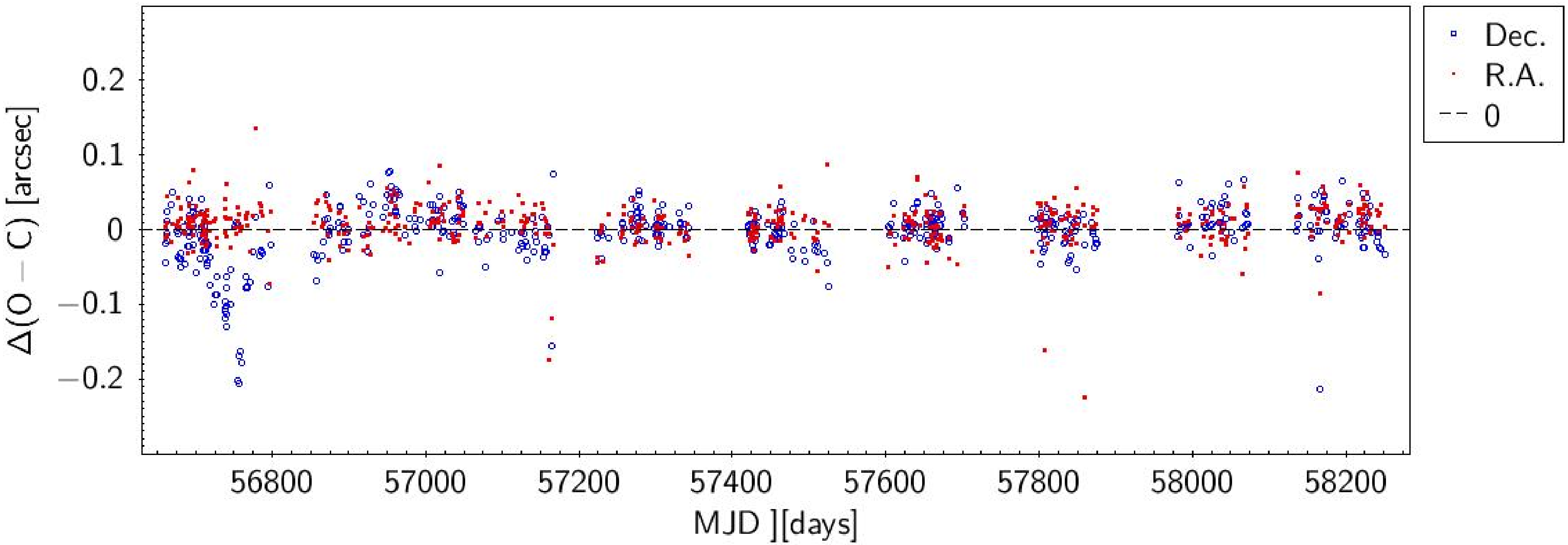
Gaia DR1 sky coverage



Gaia (more or less) travels along the ecliptic, i.e. were the sky coverage of Gaia following the NSL is worst, and in DR1 has many holes, density variations, etc. This may also have an influence on datasets (however, GBOT hasn't found anything catastrophic)

Conclusions&Outlook

- In order to assess and remedy the secondary effects, GBOT is currently continuing the analysis using the second set of Gaia data, which includes 5 par astrometry and photometry:
  - we've come 90% of the way, and the last 10% being tackled.
  - Gaia DR2 was released on April 25, so too early for firm-footed results, but as a breaking news:



Chapter 2

The GBOT Asteroid programme

The GBOT Asteroid programme

- GBOT observations take place near the ecliptic, more or less opposite to the Sun's position
  - Many main belt asteroids in the field, close to opposition
    - At their brightest, i.e. better detectability
    - Observations near opposition essential for determination of absolute magnitude, since brightness increase in this phase greater than expected from geometry
    - Gaia cannot observe in this region
- Search GBOT observations for asteroids (both known and new objects)

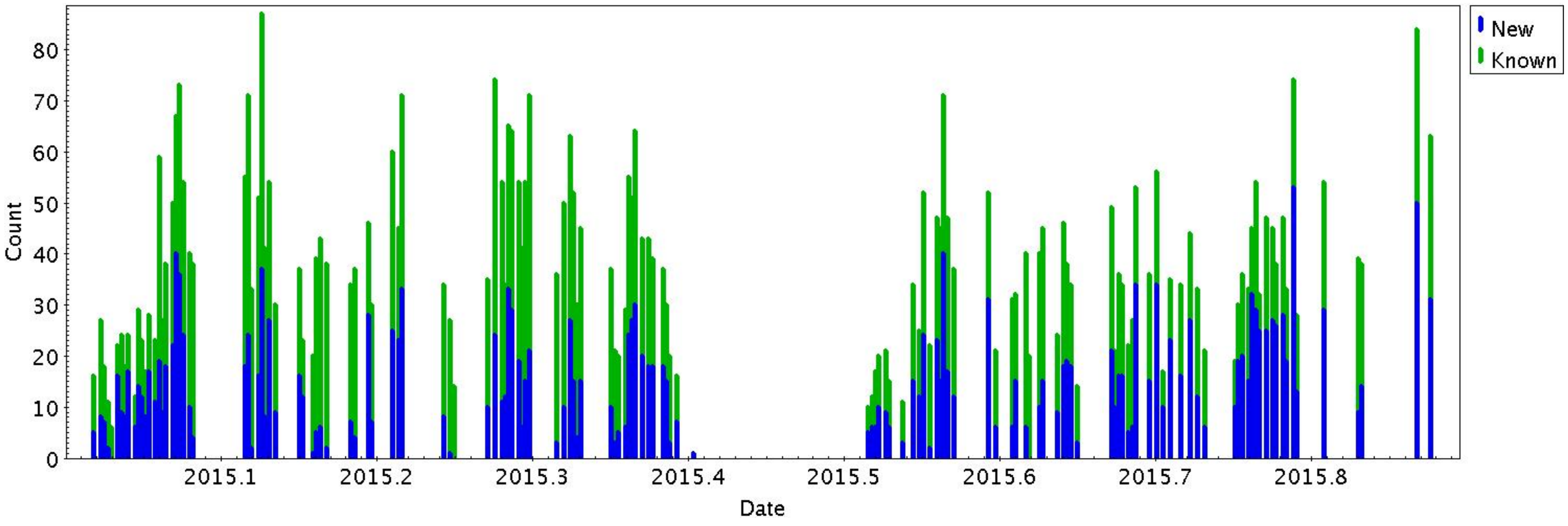
So, the GBOT Asteroid Programme was born !!

The GBOT Asteroid programme

- GBOT Asteroid programme active since beginning 2015
- Since early 2016 LT is added to programme
- Old data from 2014 added
- Following the revised GBOT observing strategy, observations are done Feb-mid-May&Aug-Nov (Gaia's cMW transit time (mid-May-mid_July) is useless for asteroid detection anyway
- All finds sent to MPC and GaiaFUN-SSO
- Daily tally 10-90 objects (VST)
- Total number of observed objects (15.05.2018):
  - 18962 all
  - 8975 new (4 observed twice)
  - 10017 known

The GBOT Asteroid programme

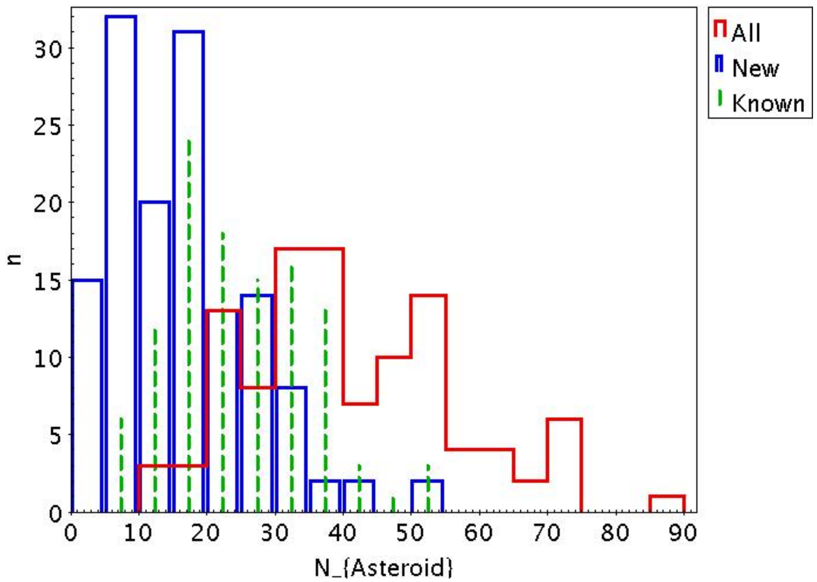
- Some Statistics:

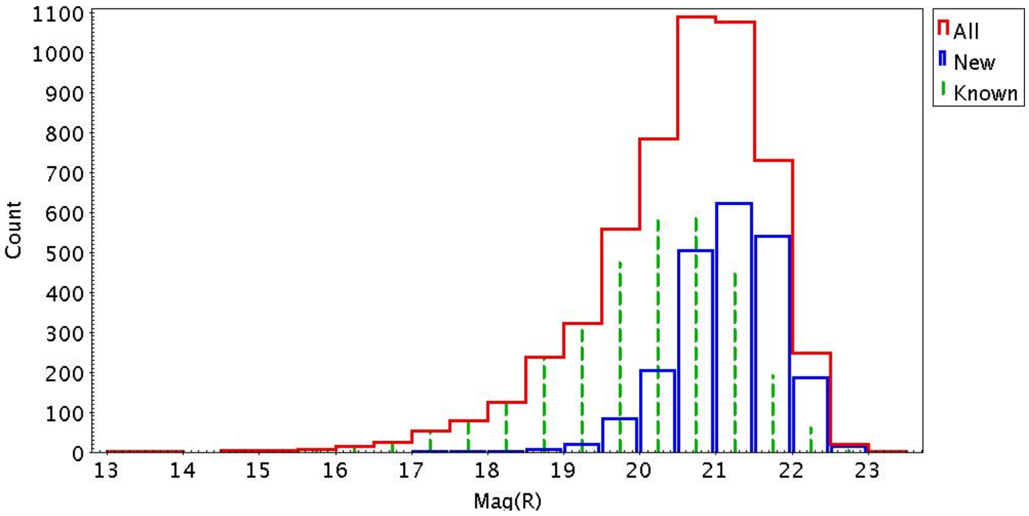


Observing timeline 2015 (for 2016: good data in February, large gaps in March/April due to GTO@VST, and El Niňo related bad weather)

The GBOT Asteroid programme

- Some Statistics:



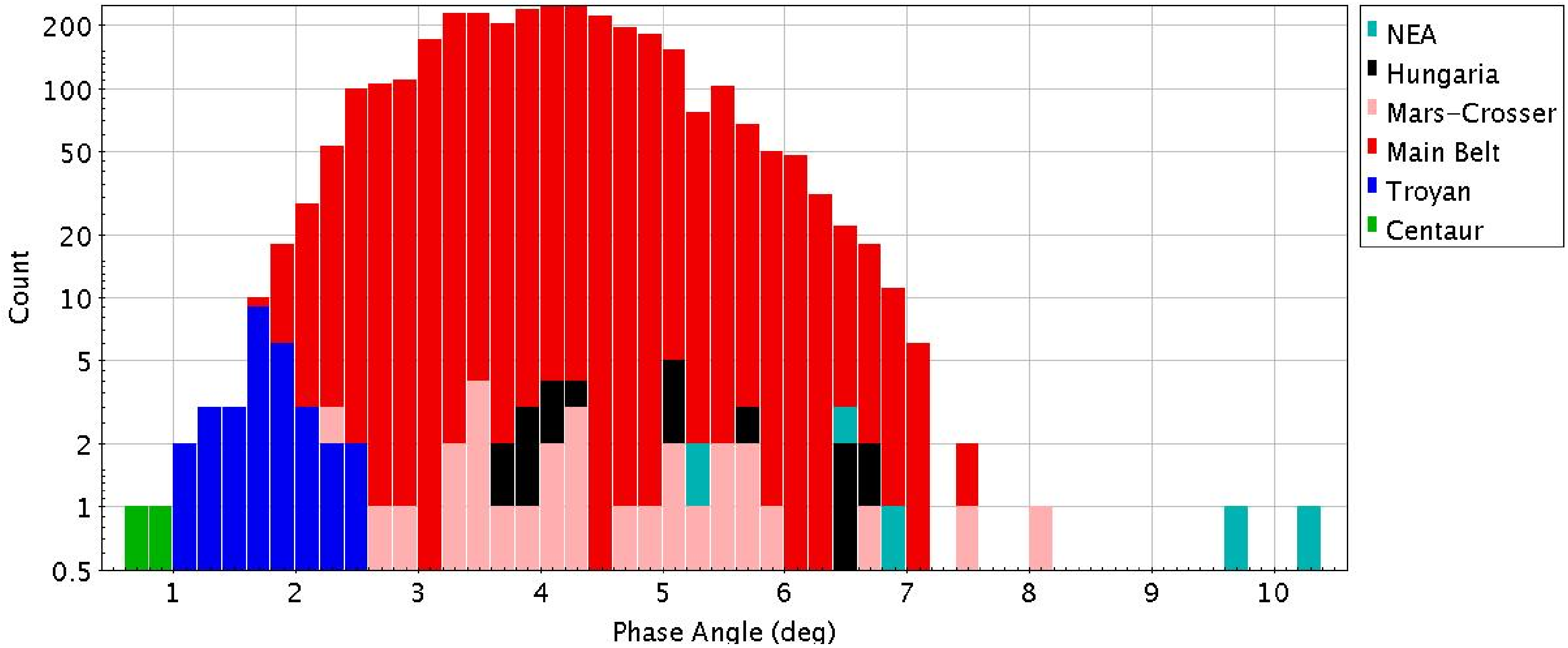


Left: nightly bounty

right: magnitude distribution

The GBOT Asteroid programme

- The Nature of our objects (known only):



Mostly Main Belt, but all types present

The GBOT Asteroid programme

- Near Earth Objects:
  - 4 NEO alerts
  - 7 confirmed NEO:
    - 2018 HR3
    - 2018 GW
    - 2018 DR1
    - 2017 UQ51
    - 2017 UA43
    - 2016 TV10 (co-disc.)
    - 2016 EK85
  - At least 1 Mars crosser
- Problem: lack of follow up (also for „normal“ asteroids)

The GBOT Asteroid programme

Our proposal: multi-passband *g'r'i'z'* photometric and astrometric follow up observations of GBOT asteroids

- Characterisation of known objects
- Follow up confirming astrometry of new objects

- First attempts as TOO-Hard unsuccessful
- For P101, new strategy devised, filler mode instead of TOO-hard mode, successful
- Observations started in April 2018

The GBOT Asteroid programme

Chain of events:

Night 1: regular GBOT observations obtained & downloaded & processed by GBOT (GBOT: no proprietory time constraints) – 13:00CE(S)T

1st ephemeris+OB created using image central coordinates and typical MBA motion – 13:10

Automated Aste-roid Candidate Extraction (Hough transform)

2nd Ephemeride +OB produced based on Barycentre of motion of extracted objects (with some clipping Applied) 13:30

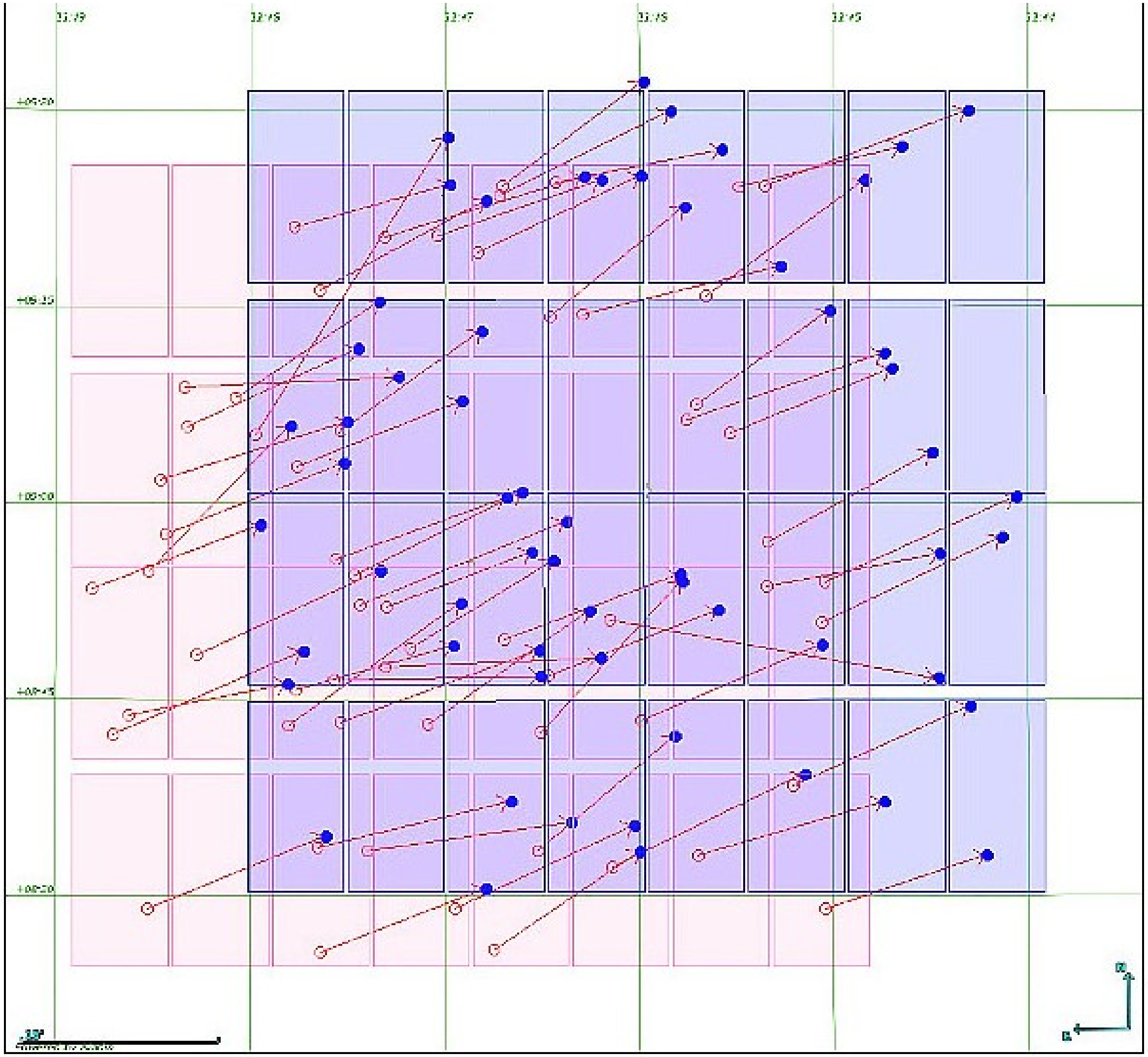
Inspection and validation of Candidates by Eye.

3rd ephemeride + OB

Submission of “best” EPH+OB To ESO via obximport – 15:00

15:30: insertion into observing Queue: lifetime of OB: 48 hrs

The GBOT Asteroid programme



Shift of MBA barycentre after 24 hrs of GBOT observations – FOV indicated by VST-OMEGACAM footprint (datapoints taken from real night)

The GBOT Asteroid programme

- Thusfar 17 nights in the period 3.4.-15.5.2018
  - 739 objects found, 433 known, 306 new 2nd epoch observations
  - Re-detection rate a bit below expectations and theoretical assumptions – reason under debate
- During our next GBOT meeting (18.-22.6. in Paris we will have a (internal) workshop, discussing our findings)

Chapter 3

The GBOT Asteroid programme as a use-case for the VST in the era of large surveys

The GBOT Asteroid usecase

- Gaia, LSST and other new and upcoming surveys scan the complete sky in relatively short times (Gaia: few weeks, LSST ~1 week)
- Follow a strict and usually inflexible scanning pattern
  - Good to discover things
  - Not so good for timely follow up
- 0.25 – 1 square degrees instruments (WFI, OMEGACAM) well suited for “field follow up” (opposed to single object follow up)
  - Example for “field follow up”: our GBOT asteroid project
  - Others could be: Variable stars in a certain MW-region (e.g. cluster, LMC)

The GBOT Asteroid usecase

As our GBOT Asteroid follow up programme demonstrates:

- Facilities like the VST/OMEGACAM can provide timely follow up of multiple objects for whole sky scanning projects
- Telescope and fields are smaller
- The strategy will be decisive!
  - Which fields to follow up
  - How long?
  - Exposure times, filters, etc
  - Non-standard techniques, e.g, polarimetry

Acknowledgements

- DLR, CNES and other funding agencies for funding the Gaia project, and thus many positions
- ESO for generously granting GBOT time on the VST
  - Proposals: 092.B-165, 093.B-0236, 094.B-0181, 095.B-0046, 096.B-0162, 097.B-0304, 098.B-0030, 099.B-0034, 0100.B-0131, 0101.B-0156 (all: GBOT)
  - The asteroid follow up proposal is 0101.C-0296
  - Monika Petr-Gotzens (ESO) for her assistance during all of GBOT
  - Michael Hilker (ESO) for his assistance in makin the asteroid follow up happen

Epilogue

Italy may have a “five star movement” ….

… but we (Gaia) have the motions of 1.3 billion stars (“movimento 1.3 billione estelle”)