ESF Research Networking Programmes Short Visit Grant

Scientific Report

Application 6173
7th GBOT Meeting - Ground-based Optical Spacecraft Tracking
4 days from 27/11/2013
Dr. Alexandre Humberto Andrei, University of Hertfordshire, Hatfield, UK

1. Purpose of the visit

Gaia's unprecedented ambitions regarding astrometric accuracy and precision require a level of knowledge of the position and velocity vector of the satellite itself not required in other satellite mission. Thus the usual methods of determining these quantities do not suffice and new approaches must be invoked. One of these is the Ground Based Optical Tracking (GBOT) for which a Working Package was formed. There are two main reasons for these high precision needs:
1. Global astrometry is severely affected by aberration, caused by the finite nature of the speed of light. This is a large effect, which means that in order to correct for aberration in the precision regime of Gaia (i.e. a few microarcseconds), the motion of the detector and hence the satellite must be known to very great precision. The resulting tolerance in Gaia's velocity vector is 2.5 mm/s.
2. Apart from stars, Gaia will also measure faint Solar System objects. These are several orders of magnitude closer than even the closest stars, their distances being comparable to Earth's distance to the Sun. Errors in the baseline therefore have a far larger effect on the precision of the parallax of an asteroid than they have on stars, meaning that if Gaia is to measure sufficiently precise parallaxes to these objects, the 3D position of Gaia itself needs to be known to about 150 m.

The 7th GBOT Meeting, at Heidelberg/GE, from 27th to 29th of November of 2013, was scheduled to the verge of Gaia's launch to review the whole operational chain of GBOT.

2. Description of the work carried out during the visit

The astrometric requirements that need to be reached for the space position and motion of the Gaia satellite are: 2.5 mm/s (r.m.s.) per coordinate (1 mm/s systematic error); and 0.15 km (r.m.s.) per coordinate. Gaia's location roundabout the L2 of the Sun-Earth rotating system is approximately 1.5 million km from the earth facing roughly opposite the Sun. At this distance the requirements of 150 m and 2.5 mm/s translate to 20.6 mas in position and 29.7 mas/day (1.24 mas/hr, 0.00034 mas/s) for the velocity tolerance. Therefore the minimal requirement is a 20 mas/measurement once a day. However to minimise all possible detrimental influences originating from our knowledge of Gaia's orbit we commit ourselves to achieving a precision of 10 mas. These values are based on GAIA-CA-TN-ESA-MP-012-2 (Perryman, 2005) and GAIA-FM-023 (Mignard, 2005). MOC has agreed to deliver (as a requirement) a precision of 6 km and 8 mm/s using Doppler and range tracking techniques. The remaining precision gap will need to be filled by astrometric observations from the ground.

The maximum expected diurnal motion of Gaia is 2 degrees/day, i.e. 7200"/day. This corresponds to 0.083"/sec or 83 mas/sec. Our limit is 10 mas/sec, hence a requirement of the observing time stamps being both accurate and precise to 0.1 sec will be sufficient. For a variety of reasons, demanding better time stamps from the participating observatories than 0.1 sec would in most cases involve severe technical adjustments and maybe even investments, that most of them will not be able or willing to perform. Even then more than 0.01 sec absolute will be illusory. Even reaching 0.1 secs will require some adaptations in the telescope operating system in many cases.

The final "exactness" (i.e. accuracy and precision) of 10 mas will only be reached after the positions of the background stars in respect to which the position of Gaia will be measured have reached this degrees of exactness. This means that we can only reach the full exactness when we have an actual Gaia catalogue available, i.e. after the first AGIS, i.e. approximately 2 years after Gaia's launch. Before that, we will have preliminary data with the required internal precision but an overall degraded accuracy based on the far worse precision of the reference stars. The exactness in this initial phase will be something like 50-100 mas (possibly more since the available reference catalogues often have overall shifts in respect to the current reference system). These data will be used by MOC to verify their orbit determination.

After the first AGIS, the data from the first two years will be re-evaluated using the now sufficiently precise reference points and these final data will be then again added to the database, substituting the preliminary data. All data which will be obtained after the first AGIS will immediately feature full precision and thus be added to the database as final data.

We will deliver ICRS based topocentric astrometric coordinates of every measurement. We ourselves cannot transfer topocentric coordinates to geocentric ones, since we do not know the precise distance to Gaia. This will then have to be done by Flight dynamics, who will then also averade a given days individual measurements to one data point (Again we cannot do that, since topocentric coordinates of a closeby object, such as Gaia are subject to parallax due to the earths rotation and subsequent displacement of the observer in respect to the target. This parallax causes objects not to move in an almost straight line, but more or less in a ribbon form.).

We will determine coordinates against an ICRS based catalogue, such as PPMXL (later it will be the Gaia catalogue), proper motion corrected to the epoch of the observations (using barycentric ICRS coordinates). The resultant coordinates will then be topocentric but with aberration already corrected, and in the standard coordinate system (ICRS). The ICRS also spares us complications such as arising from precession, nutation, earth rotation etc.

The GBOT crew commits itself to weekly deliveries for a few (4 to 6) weeks starting with L2 insertion. The deliveries should comprise all available recent observations. ESOC will give weekly feedbacks to GBOT about their findings from the data. Side remark: It would be good to have the GBOT deliveries on the day before the weekly reconstruction run at ESOC.

For the rest of the mission, GBOT will do monthly deliveries, again containing all available recent observations. Side remark: Observations that are older than about four weeks at the time of delivery are no longer of interest for the weekly orbit reconstruction and prediction process. They may in principle wait for the second-iteration delivery.

For the data analysis we have developed a whole infrastructure, developing observing techniques, a dedicated software pipeline, a database. The actual observations will be made by a small pool of observatories on both hemispheres. To their recruitment and assessment of capabilities, a questionnaire and perform tests were developped. The backbone of the data will be supplied by the 2 m Liverpool telescope located on La Palma, Canary Island, Spain, and the Las Cumbres Optical Global Telescope Network (LCOGT.net), which operates 1 m telescopes in Chile, South Africa, Australia and

Texas. We will also have some support from ESO's VST (the 2.6 m telescope at Paranal, Chile) and additional facilities will also provide data when needed.

During the 7th GBOT Meeting, aim of this visit, all such procedures and protocols were reviewed. In special the initial day was dedicated to the core group, in charge of critically assess every observation incoming from the partner observatories, and prepare the data output to MOC, to discuss each detail of this 5 years commitment.

3. Description of the main results obtained

The work was focused along the following main topics:
i) Database & Software readiness for operations - a hands on exercise simulated the access to the main database, in the Observatory of Paris, and the analysis tools available.
ii) Partners readiness - The 2m. Liverpool Tobotic Telescope (La Palma, Spain) and the Las Cumbre 1m. Telescopes (immediately those in Chile and Texas, EUA) are ready to operate on regular basis. The pros and cons of pre-warning the observatories about adverse times for data acquisition (e.g., bright star along the satellite path) were further debated.
iii) Hardware - The plans for a mirror database, duplicating the main one at Paris Observatory, were updated.
iv) Diagnostics - The existing tools were updated. An important decision was reached about including the raw science and detrending images in the GBOT database.
v) RadioGBOT - The science of VLBI network time demand was updated. A decision was reached to make combining optical observations of the Gaia satellite and of the reference quasar near-simultaneously with the VLBI observations.

The daily schedule was as follows:
i) Wednesday, November 27th - Core data reduction team workshop. GBOT daily operations school hands on exercise.
ii) Thursday, November 28th -
09:5019: Welcoming address, organisational things, by M. Altmann
10:00: GBOT, shortly after the Gaia launch, by M. Altmann
10:20: Gaia news, by T.Prusti
10:40 10: Brown Dwarfs chronometers of the Galaxy, by R. Smart
11:45: GBOT pipeline/database readiness report, by S. Bouquillon, F. Taris, C. Barache
12:15: GBOT/SOC interfaces status, by S. Els
14:00: Radio GBOT, by L. Gurvits
14:30: Plenary round: Daily chores, duty roster, etc
16:30: Plenary round, including GBOT activities in the launch
iii) Friday, November 29th -
09:30Discussions, decisions, and planning ahead
09:30: GBOT Publications
11:00: Immediate actions, and wrapping up
13:00: Splinter meeting on the LT asteroid observations
1300: Splinter meeting on the next developments on the reduction pipeline

4. Future collaboration with host institution

The GBOT will continue along the 5 years of the Gaia mission. So will naturally continue the collaboration with ARI Heidelberg, home of the GBOT Coordinator.
During Gaia operational phase some particular stances may be remarked:

i) During commissioning phase, the GBOT, starting on as from January 7th 2014, will deliver to MOC weekly data results of the satellite position and movement, based on astrometric results referred to the PPMXL. This will be in charge of the Paris section and the Coordinator.
ii) During regular times the data results delivery to MOC will be monthly, and the task chores will be taken on turns by sub-teams of all the 5 core members, with a reserve sub-team on alert.
iii) Observatories partner recruitment and maintaining will continue throughout the operational phase (since we might/will loose partners). Thus the questionnaires and performance tests will continuously be analyzed.
iv) For the Observatories in the partnership, regular progress reports are going to b e issued.
v) Software optimization will continue at least until first AGIS.
vi) After 1st AGIS, all data taken before will need to be rereduced. This will be done after each release of a nerw version of the provisionals Gaia catalogs. And of course a final rereduction at the end of the mission.

5. Projected publications / articles resulting or to result from the grant

Given the amount of work invested into the GBOT campaign and especially the pipeline, which can also be used for work outside of GBOT, e.g. astrometry of other satellites or asteroids, 2 refereed papers are going to be prepared:

i) General GBOT paper. This will steam off from the "astrometry" Technical Note. It will thus discuss the bearing of astrometric effects, at the mas-level, for probes, but also for moving objects, like those of the Solar System. Gaia itself will the test probe for the first case, while the asteroid observations taken at the Liverpool Telescope will thus be in the Solar System case. This paper will describe the GBOT Project, the reasons for GBOT, tests and their results illustrating properties of e.g. reference catalogues, centering algorithms, as far as of interest to a general astronomer, the overall structure of GBOT. The experiences for GBOT for other observing efforts will be outlined, pointing out to the fact, that similar campaigns, with other objectives, but similar methods will become more frequent.

ii) Pipeline paper. This steam from the pipeline presentations at different symposia. The key point is how to address precision when accuracy is guaranteed by the Gaia catalogue. Naturally this a novelty, given the present ground-based rooted catalogs, and consequently practice of never targeting for top precision on large basis, but only in very small, local, repeated fields. The GBOT team has developed a software pipeline, to tackle the challenge to derive high quality astrometry of a faint moving object, i.e. from short exposures coming from several sources of different characteristics. A description of the software, its features, the reduction steps etc. will be given in this paper. Also the database system organising and keeping up a project lasting several years will be described.

Preferably especially for the reason of "referability" both papers should be published in the same Journal and if possible the same issue, if not in adjacent issues.

A third or a series of result papers will also be prepared with the full length results, light-curves and an analysis of asteroids taken at the Liverpool Robotic Telescope.

University of Hertfordshire, Hatfield, UK

December 18th, 2013

Alexandre Humberto Andrei, MSc, PhD, Gaia/DPAC

Appendix 1. Travel and Expenses Tables

Table 1: Travels

Item	Trip	Date	Depart	Arrival	Carrier
1	Start from U.H.	27/11/2013	02:00		own means
2	Hatfield-London	27/11/2013	03:20	04:10	National Express coach
3	London-Frankfurt	27/11/2013	06:50	07:20	RyanAir (airplane)
4	Frankfurt-Heidelberg	27/11/2013	09:20	11:30	Hahn Express coach
5	Heidelberg mountain observatory	28/11/2013	09:00	18:00	city bus
6	Heidelberg-Frankfurt	29/11/2013	14:30	16:40	Hahn Express coach
7	Frankfurt-London	29/11/2013	19:30	20:00	RyanAir (airplane)
8	London-Hatfield	29-30/11/2013	23:30	00:15	National Express coach
9	Arrival at U.H.	30/11/203		01:00	own means

Table 2: Expenditures

Item	Expenditure	Cost	Obs
1	National Express coach return trip Hatfiled-London	E$17.28	GBP$14,40
2	RyanAir return trip London-Frankfurt	E$48.94	GBP$40.78
3	Hahn Express return trip Frankfurt-Heidelberg	E$36.00	
4	Hotel Jugendherberge Heidelberg - 3 nights	E97.60	
5	City bus (trip to mountain observatory)	E$2.30	
6	LIDL supermarket	E$9,20	
7	Zum Roten Ochsen restaurant	E$93.80	
8	LIDL supermarket	E$22.62	
9	Small expenses up to the limit of E$85/day	E$212.08	
ALLOWANCE (4days)		E$437,60	
TRAVEL EXPNSES		E$102.22	
TOTAL		E$539.82	

Appendix 2. Host's Evaluation

STATEMENT FORM

Gaia's unprecedented ambitions regarding astrometric accuracy and precision require a level of knowledge of the position and velocity vector of the satellite itself not required in other satellite mission. Thus the usual methods of determining these quantities do not suffice and new approaches must be invoked. One of these is the Ground Based Optical Tracking (GBOT) for which a Working Package was formed. There are two main reasons for these high precision needs:

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This was the 7th workshop of the GBOT WP (besides the regular monthly telecons), held at the Astronomisches Rechen-Institut (**ARI**), at Heidelberg, on November 27th-29th. It was of particular importance, because of the imminent launch of Gaia, on forthcoming December 19th. On this meeting were reviewed and further discussed the strategies and steps for control, record, and analysis of the daily observations of the probe during the mission. Additionally, the planning for next publications was also discussed, as well as cases of science application such as Radio-GBOT and Asteroids.

Alexandre Andrei is a member of the WP, and member of the operational core. Therefore his presence to the meeting was highly necessary. The meeting was successful and the technical and scientific goals were reached.

Martin Altmann

GBOT Coordinator - ARI/DPAC/GAIA

Appendix 3. Expenses Receipts

11/25/13 National Express Booking

national express

Find a Journey Choose your Ticket Add Extras Pa

Confirmation Back to

Journey Ref Outbound: OVTA-01-3EBAF
Journey Ref Return: DPVM-01-57640

Thanks, your booking is confirmed.

Click here to print your ticket.

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You will need to show your printed ticket to the driver as you board every coach.

We hope you enjoy your journey.

For ticket validation

Your booking is complete Cli
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Express booking!

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By clicking above, you can claim
preferred partner when you join t
conditions apply

Lead Passenger:	Dr A.H. Andrei 1 Adult
Ticket number:	ETCABT64
Ticket type:	RETURN

Tickets:	£13.40
Booking Fee:	£1.00
e-Ticket:	free
Total	£14.40

Payment taken from your Acc
£14.40 has been charged to your card ****

An email has been sent to
oat1aha@gmail.com
with a detailed confirmation of all items in your booking.

coach.nationalexpress.com/nxbooking/travel-receipt?printKey=dfb2fed490cce468&ticketNumber=ETCABT64#

11/25/13 National Express Booking

Leaving: Hatfield to STANSTED AIRPORT LONDON.

Date of travel	Departure	Arrive	From	To
Wed 27 Nov 2013	03:20 (3:20 AM)	04:10 (4:10 AM)	Hatfield The Galleria, Cavendish Way View on map	STANS LONDO Coach Stn, View on m

Returning: STANSTED AIRPORT LONDON to Hatfield.

Date of travel	Departure	Arrive	From	To
Fri 29 Nov 2013	23:30 (11:30 PM)	00:15 (12:15 AM)	STANSTED AIRPORT LONDON Coach Stn, Bay 19 View on map	Hatfield The Galleri View on m

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10/23/13 Webmail ON :: Alexandre Andrei, 27-29 Nov 13, Ryanair Travel Itinerary - Don't Forget You MUST Check-in Online and Print Of

FLIGHT RESERVATION NUMBER
OI86QJ
FLIGHT STATUS CONFIRMED

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PLEASE CHECK YOUR FLIGHT(S) AND PASSENGER(S) DETAILS BELOW.

FLIGHT(S) DETAILS

From London-Stansted to Frankfurt-Hahn (FR 754)

DEPART (STN)	ARRIVAL (HHN)
London-Stansted	Frankfurt-Hahn
Wed 27 Nov 2013	Wed 27 Nov 2013
07:20hrs	09:40hrs

Book Airport carpark Airport transfers Car hire

From Frankfurt-Hahn to London-Stansted (FR 757)

DEPART (HHN)	ARRIVAL (STN)
Frankfurt-Hahn	London-Stansted
Fri 29 Nov 2013	Fri 29 Nov 2013
20:00hrs	20:20hrs

Book Airport transfers Reserved seating Priority boarding

PASSENGER(S)

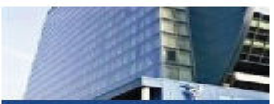
Mr ALEXANDRE ANDREI
No Travel Insurance? Maybe you should add

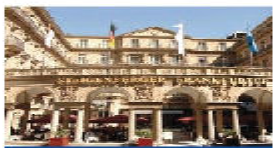
You must check-in online and print your boarding pass on an individual A4 page for presentation at both airport security and at the boarding gate. You can check-in online from 15 days up to 4 hours prior to your scheduled flight departure.

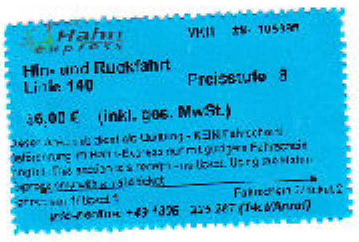
If you have a query about our services or policies please check our Frequently Asked Questions
1. What is cabin baggage allowance?
2. How do I check-in online?
3. Can I change a flight date, time, route?

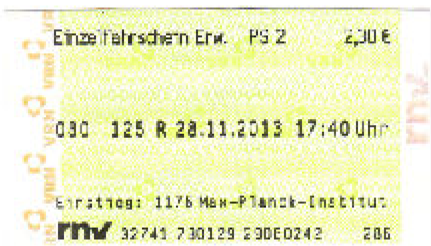
PAYMENT DETAILS

Total Fare	16.23 GBP
Taxes, Fees & Charges	0.00 GBP
EU 261 Levy	2.50 GBP
Web Check in	7.00 GBP
ETS	0.25 GBP
Administration Fee	14.00 GBP
Credit Card Fee	0.80 GBP
Payment method	VI
Account name	coop group
Card number	...XXXX 8854
Payment amount	40.78 GBP
Total paid	**40.78 GBP**









Register No. 152708/1113
(please always state)

Jugendherberge Heidelberg
Tiergartenstraße 5
69120 Heidelberg

Phone: 06221 / 65119-0
Telefax: 06221 / 65119-28

Leitung: Martina & Andreas Rihm
jhheidelberg@jugendherberge.de

Bank:
Bezirkssparkasse Heidelberg
IBAN: DE56 6725 0020 0000 5032 07
BIC: SOLADES1HDB

Jugendherberge Heidelberg Tiergartenstraße 5 * 69120 Heidelberg

Alexandre Humberto Andrei

STIR - University of Hertfordshire, Coll

GB-AL10 9AB Hatfield Herts
GROSSBRITANNIEN UND NORDIRLAND

Invoice

Date: 27.11.13 18:52 Page: 1
Invoice: 001/00339233
Tax No.: 99015/07088

Your stay: 27.11.13 - 29.11.13

Date	Article	Description	Quantity	Price	Total	Tax
27.11.13	240	Accomm./breakf./27+ 1st.night	1	30,10	30,10	*
		UN 7,00 %: 24,60 VE 19,00 %: 5,50				
27.11.13	196	Surchage for single occupation 27pl&		11,00	22,00	7
27.11.13	364	key deposit	1	10,00	10,00	0
27.11.13	699	Service fee	1	1,70	1,70	0
27.11.13	710	Welcome Stamp	2	3,50	7,00	0
28.11.13	241	Accomm./breakf./27+ 2nd.night	1	26,80	26,80	*
		UN 7,00 %: 21,30 VE 19,00 %: 5,50				

Net:	18,70	0,00	MwSt	0,00 %	
Net:	63,46	4,44	MwSt	7,00 %	
Net:	9,24	1,76	MwSt	19,00 %	
Grand Total:		gross	EURO	97,60	
		BAR	EURO	108,00	
		ZURUCK	EURO	-10,40	

Thank you for your stay!

Thank you for your stay!

Invoice accepted / Signature

Place of jurisdiction is Stuttgart

LIDL

Brückenstraße 47
69120 HD-Neuenheim
MO - SA 8 - 21 Uhr SO geschlossen

	EUR
Geflü.-Leberw. 2er	1,79 A
Pommersche Schnittl.	1,79 A
Pommersche Apfel	1,79 A
Grobe Teewurst	1,79 A
Pfälzer Leberwurst	1,49 A
Vollkorn Toast	0,55 A

zu zahlen 9,20

Bar 10,20
Rückgeld -1,00

MWST%	MWST	+	Netto	=	Brutto
A 7 %	0,60		8,60		9,20
Summe	0,60		8,60		9,20

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UST-ID-NR: DE813389133
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Tisch: 11.0
20.11.2013

Bed. 4 Rg.: 31

2 x 4.60	
Spätburgunder	9.20
Weihnachtsbier 0,3l	3.90
Cola light 0,3l	3.00
Schweineschnitzel	3.90
2 x 13.90	13.50
Kurpfälzteller	
Kimmelcraler	27.80
4 x 5.90	12.60
A-Strudel m. V-Eis	
	23.60

ENTHALTENE MWST 19% : 14.98 EUR
SUMME NETTO (19%): 78.82 EUR
SUMME BRUTTO (19%): 93.80 EUR

Summe : 93.80 EUR

BAR GEGEBEN: 93.80 EUR

St.Nr.32420/20004

Vielen Dank für Ihren Besuch.

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69120 HD-Neuenheim
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	EUR
Bananen	0,50 A
0,424 kg x 1,19 EUR/kg	
Gurken	0,45 A
Staudentomaten	0,88 A
Mozzarella	0,55 A
Herta Putenbr. ger.	2,79 A
Grünländer Nussig	1,39 A
Nescafé Klassik	3,30 A
2 x 1,65	
Spaghetti 500g	0,49 A
Frühlingseier S-XL	1,55 A
Kaffeepads Crema	1,49 A
Mandel-Nuss-Flakes	1,29 A
Dekor Winterzauber	1,65 A
Laktosefreie H-Milch	1,90 A
2 x 0,95	
Gehackte Tomaten	0,46 A
Mixxed Up	0,70 B
2 x 0,35	
Pfand 0,25	0,50 B
2 x 0,25	
Big Sandwich Toast	0,85 A
Rexona Invisible	1,75 B

zu zahlen 22,62

Bar 50,00
Rückgeld -27,38

MWST%	MWST	+	Netto	=	Brutto
A 7 %	1,29		18,38		19,67
B 19 %	0,47		2,48		2,95
Summe	1,76		20,86		22,62

3481 567385/01 20.11.13 18:17

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