

Scientific Report

QSO Astrophysics, Fundamental physics, and Astrometric Cosmology in the Gaia era



GREAT-ESF workshop

6-9 June 2011

Faculty of Sciences of the
University of Porto



**EUROPEAN
SCIENCE
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SETTING SCIENCE AGENDAS FOR EUROPE



FCT Fundação para a Ciência e a Tecnologia
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Summary

Gaia will survey with unprecedented accuracy approximately 500,000 QSOs, largely new detections. Besides the implications for QSO science, this sample will allow the best materialization ever of a reference frame, providing astrometry with the potential for testing General Relativity and probing modern Cosmology. These subjects were discussed at the **QSO Astrophysics, Fundamental physics, and Astrometric Cosmology in the Gaia era** workshop, along 4 days of an intense scientific program comprising 16 review talks, 23 contributing talks, 2 posters, plus 2 splinter meetings and a concluding discussion session. That involved the participation of 54 researchers (including 5 PhD students) that came from Belgium, Canada, France, Germany, The Netherlands, Hungary, Italy, Portugal, Republic of Korea, Spain and U.S.A.

The workshop was funded by GREAT-ESF, and had two sponsors: the Observatory of Torino and the Faculty of Sciences of the University of Porto. The funds supported the hotel expenses of 17 participants, the trip expenses of 15 participants, and the coffee breaks, lunches and conference dinner for all the participants.

General information is available at:

<http://www.fc.up.pt/great-ws-porto>

The list of Participants can be found at:

<http://www.fc.up.pt/great-ws-porto/participants.html>

Both the program and the presentations are on line (PDF files), at :

<http://www.fc.up.pt/great-ws-porto/program.html>

Description of the scientific content of and discussion at the event

The program was divided in 4 sessions, along 4 days, namely: **QSO astrometry in the context of observational astrophysics**, consisting on 4 review talks and 10 contributed talks; **QSO, Reference Frame and the fabric of Space-Time** with 4 review talks and 7 contributed talks; **Astrometric Cosmology**, with 6 review talks and 4 contributed talks; **Epistemology Implications of current theories of the Universe** with 2 review talks. The meeting closed with a general discussion session on all the subjects debated along the 4 days.

Following a summary of the subjects addressed in the workshop:

QSO astrometry in the context of observational astrophysics

Gaia will permit, for the first time, a combination of astrometric accuracy with multi-epoch photometry, for a large (all-sky) sample of quasars, at optical band. The stability of photo-centres at μas scales, the optical-radio core shift in AGNs are subjects that were addressed by their own and also in the framework of the determination of the extragalactic celestial reference frame at optical bands.

Four review talks summarised some of the fundamental aspects related to QSO astrometry. Francois Mignard talk was focus on the recognition of AGNs with Gaia; Ian Browne discussed how radio and optical astrometry might have an impact on AGN astrophysics knowledge, Norbert Bartel summarised the relevance of VLBI astrometry for astrophysics, celestial reference frames, and general relativity; Valeri Makarov review the "Quasometry", ie the use of quasars in global astrometry, and Patrick Charlot presented the current status of the International Celestial Reference Frame, and discuss the future one. We had 7 contributed talks. Alexandre Andrei, Sonia Antón, Francois Taris and Kenneth Johnston presented results about the stability of QSO astrometric positions, and its interpretation in terms of AGN components. Kirril Sokolovsky, Andrei Lobanov, Richard Porcas, Say Frey and Geraldine Bourda discussed the astrophysical processes that might limit the astrometric alignment of radio and optical cores of individual QSOs, the issues on radio and optical reference-frame alignment, and present some projects on radio observations in preparation to the alignment with the future Gaia frame. Yassine Damerджи presented the Gaia Quasar Classifier. Francois Finet and Brigitte Rocca-Volmerange discussed how Gaia observations may be important for subjects like gravitational lenses and star forming galaxies, respectively. Alexandre Andrei, Jean Souchay presented work on quasar astrometric catalogues and Francois Mignard put forward the idea of turning the Gaia Reference frame in to the next ICRF.

QSO, Reference Frame and the fabric of Space-Time

Gaia catalogue of QSOs represents a high-accuracy materialization of some relativistic reference system. Since General Relativity is the theory needed to build the reference frame at μas and sub- μas accuracy, the relativistic astrometric models in Gaia and their link to the reference frames must be considered. Moreover, high precision astrometry of extragalactic and galactic objects is a powerful tool for providing independent experimental grounds to the most daunting challenges in fundamental physics and cosmology. These aspects were thoroughly discussed in this session.

There were four review talks, namely, from Sergei Klioner and Sergei Kopeikin, that discussed the theoretical foundations of the relativistic model for high accuracy

astrometric observations and underlying astronomical relativistic reference systems; its application to astrometry, Gaia and beyond; Donato Bini and Fernando de Felice discussed about the reference frames and theory of measurements in General Relativity, the observer's protocol in 3+1 space-time splitting, geometrical and physical properties; application to astrometry, photon's orbit around BH and accretion disk; drag effects around the Earth. The four contributed talks presented work on: detection of a gravitomagnetic effect of the reference frame on Earth and the role of VLBI by Matteo Ruggiero, the Time Transfer Function, as a new not integrative method for calculating the propagation direction of light by Pierre Teyssandier and Stefano Bertone, and on the geometrical accuracy and light tracing problem in physical measurements, as well as on the consistency with the geometrical interpretation due to the GR and connection with the existent approaches, by Mariateresa Crosta.

Astrometric Cosmology

At zero redshift, dealing with local cosmology, accurate absolute motions of stars within our Galaxy will provide access to the cosmological signatures in the disk and halo. The uniqueness offered by accurate kinematics at the scale of the Milky Way is the ability to account in situ for the predictions of the cold dark matter model, in the case of the halo, and eventually map out the distribution of dark matter or other formation mechanisms required to explain signatures recently identified in the old component of the thick disk. These subjects were presented and discussed in this session.

There were 6 review talks. Mario Lattanzi addressed issues on possible astrometric and kinematical cosmological signatures in disk and halo, the "relativistic astrometry" being a tool for local cosmology; Umami Abbas presented a review on the halo of Milky Way, large data samples and statistical properties. Salvatore Capozziello discussed $f(R)$ theory, dark matter and dark energy as signals of the breakdown of GR at large scales interpreted as a sort of curvature effects, PPN parameters and strong field astrophysical phenomena as $f(R)$ observable effects. Jorge Parámos discussed local tests of competing models to GR, extensions and alternatives to GR to tackle the origin of dark matter and dark energy. Orfeu Bertolami summarised the underlying principles of our current theories, theoretical aspects on equivalence principle's violation. There were four contributed talks. Alberto Vecchiato discussed some astrometric experiments in fundamental physics, the role of the astrometric observable in putting Einstein to test, Mario Gai presented the Gravitation Astrometric Measurement, an alternative experiment to Gaia, Giuseppe Cimo talked about : accurate astrometry for Planetary Radio Interferometry and Doppler experiment, and Paulo Freire discussed the impact of Gaia observations to Millisecond Pulsars knowledge.

Epistemology Implications of current theories of the Universe

This was a short session, that comprised 2 review talks. One by Orfeu Bertolami on the interpretation of the Universe without GR and another by Fernando de Felice on the observer's space-time puzzle as new principle of GR, exploiting the theory from the "conscious" point of view of a not anthropic observer.

Webcast talks

Triggered by some requests (mainly from USA) the Faculty of Sciences agreed on partially webcast the workshop, in a total of 6 hours, free of charge, and we chose to broadcast the first review talks of each day, namely:

6th June: 09:00 -- 09:45 Francois Mignard QSO recognition and observation with Gaia; 09:45 -- 10:30 Ian Browne AGN astrophysics from radio and optical astrometry

7th June: 09:00 -- 09:45 Sergei Klioner Astronomical relativistic reference systems and their application for astrometry; 09:45 --10:00 Sergei Kopeikin Astrometric reference frames in the solar system and beyond

8th June 09:00 -- 09:45 Mario Lattanzi Astrometric Cosmology; 09:45 --10:10 Umami Abbas The halo of Milky Way

and they are available at

<http://www.ustream.tv/channel/fcup---eventos>

Social Program

In order to make the most of the 4 days, we organised the lunches for all the participants, at the Faculty and nearby the conference room, as lunch time is the perfect time for informal discussions. It consisted on light meals, with vegetarian and non-vegetarian choices.

A conference dinner was also organised, and happened on 8th of June. Porto is located on the banks of the Douro River. The conference dinner was served in a boat while sailing along the Douro River, under the 6 main bridges that connect Porto to the other side, Vila Nova de Gaia.

Assessment of the results and impact of the event on the future direction of the field

As organisers we think that all the goals were achieved. A possible assessment of that assessment is the feed back from the participants, that is here partially shared:

I would like to thank you and Mariateresa for the fantastic workshop you have organized and your kind attention. Great Porto-Torino connection! You should repeat it more often – Ioana Sotuelo

I would like to thank you and Mariateresa for the organization: I appreciated the colloquial atmosphere of the workshop, and the possibility of having very informal discussions, which were useful for me – Matteo Ruggiero

I really wish to congratulate you two for a job well done!! The organization of the meeting has been impeccable and everything went very smoothly throughout. Three very intense and scientifically dense days ending with the far reaching talk by Orfeu and the unexpectedly interesting discussions of this morning session! ... The meeting has turned out to be of very high quality – Mario Lattanzi

Thanks very much for having organized such a nice workshop. I fully enjoyed it. Thanks also again for having invited me – Norbert Bartel

I would like to thank you and Mariateresa for the efficiency of the organization and for the high level of the contributions which all left seeds of further considerations. – Fernando de Felice

This was also an opportunity to introduce GREAT, and in particular the GREAT working groups related to the Quasars, the Reference Frames and Relativity. We received an enthusiastic feedback from the participants, and the willing to join GREAT, which was one of our goals.

The different subjects discussed during the workshop are hot topics in the pre-launch phase of Gaia, and will be so for many years after the launch. Some of the talks presented projects that aim to make the most of the Gaia data, including the preparation of large observational proposals to co-add scientific value to Gaia data. One of the many examples is the Gaia reference frame and its connection with the future International Celestial Reference Frame. We believe that this workshop helped to stimulate bridges between different groups. A clear sign of the importance of these subjects is that the workshop was accepted for publication in the **Memorie della Societa Astronomica Italiana**, the slot for the publication is Vol 83 n.3.

Acknowledgements

Sonia Antón and Mariateresa Crosta thank all the help from the SOC and LOC members, that was one of the keys for the success of the meeting, namely: Alexandre Andrei, Orfeu Bertolami, Geraldine Bourda, Ian Browne, Bruno Coelho, Patrick Charlot, Fernando de Felice , Sergei Klioner , Mario Lattanzi, Dalmiro Maia, Christophe Le Poncin-Lafitte, Francois Mignard, José Osorio.

We also thank the Faculty of Sciences of the University of Porto for hosting this workshop, all the support from the Observatory of Torino, and the financial support from the European Science Foundation – GREAT

Final Program

QSO astrometry in the context of observational astrophysics

Monday, 6th June

08:30-09:00 - **Registration & Welcome**

09:00-09:45 - **Francois Mignard** QSO recognition and observation with Gaia

09:45-10:30 - **Ian Browne** Searching for offset AGN; kicked black holes, binary black holes, gravitational lensing

10.30-11.00 - **Coffee Break**

11:00-11:20 - **Yassine Damerdji** The QSO classifier in Gaia

11:20-11:40 - **Francois Finet** Quasars and bright multiply imaged quasars detected by GAIA

11:40-12:00 - **Alexandre Andrei** GAIA Initial QSO Catalogue - The Variability and Compactness Indexes

12:00-12:20 - **Francois Taris** Optical observations of QSOs for the link of reference systems

12:20-12:40 - **Sonia Antón** Photocenter variability and AGN components

12.40-14.00 - **Lunch**

14:00-14:45 - **Norbert Bartel** VLBI astrometry for probing astrophysics, celestial reference frames, and general relativity

14:45-15:30 - **Valeri Makarov** Quasometry, Its Use and Purpose

15.30-16.00 - **Coffee Break**

16:00-16:20 - **Jacques Roland** Determination of the characteristics of the BBH system using VLBI observations

16:20-16:40 - **Andrei Lobanov** Opacity in nuclear regions of AGN: A factor for astrometry, a tool for astrophysics

16:40-17:00 - **Kirill Sokolovsky** A VLBA survey of opacity-driven positional shifts in AGN

17:00-17:20 - **Kenneth Johnston** Stability of QSO Astrometric Positions

17:20-17:40 - **Brigitte Rocca-Volmerange** AGN and Star formation from powerful radiogalaxies with Gaia

17:40-18:00 - **Christine Ducourant** The extended objects as they will be seen and treated by Gaia

QSO, Reference Frame and the fabric of Space-Time

Tuesday, 7th June

09:00-09:45 - **Sergei Klioner** Astronomical relativistic reference systems and their application for astrometry

09:45-10:30 - **Sergei Kopeikin** Astrometric reference frames in the solar system and beyond

10.30-11.00 - **Coffee Break**

11:00-11:30 - **Patrick Charlot** The ICRF now and in the future

11:30-11:50 - **Geraldine Bourda** VLBI observations to prepare the alignment with the future Gaia frame

11:50-12:10 - **Richard Porcas** Issues of radio and optical reference-frame alignment

12:10-12:30 - **Sandor Frey** Radio-optical outliers - a case study with ICRF2 and SDSS

12.30-14.00 - **Lunch**

14:00-14:20 - **Jean Souchay** The LQAC (Large Quasar Astrometric Catalogue): principle and construction

14:20-14:40 - **Francois Mignard** From the Gaia Frame to the ICRF-3

14:40-15:25 - Donato Bini **Observers, observables and frames in general relativity: applications to light propagation tracing**
15.25-15:55 - **Coffee Break**
15:55-16:40 - Fernando de Felice **Physical measurements in General Relativity**
16:40-17:00 - Matteo Luca Ruggiero **Using ring laser systems to measure gravitomagnetic effects on Earth**
17:00-17:20 - Stefano Bertone **Relativistic astrometry and Time Transfer Functions**
17:20-17:40 - Pierre Teyssandier **New methods for calculating the propagation direction of light in static, spherically symmetric space-times**
17:40-18:00 - Mariateresa Crosta **Physics and Coordinates in competition in highly accurate measurements**

Astrometric Cosmology

Wednesday, 8th June

09:00-09:45 - Mario Lattanzi **Astrometric Cosmology**
09:45-10:10 - Ummi Abbas **The halo of Milky Way**
10.10-10.40 - **Coffee Break**
10:40-11:25 - Salvatore Capozziello **Dark Energy and Dark Matter as Curvature Effects**
11:25-12:10 - Jorge Paramos **Testing a non-minimal coupling between matter and curvature and beyond**
12:10-12:30 - Alberto Vecchiato **Putting Einstein to test: astrometric experiments in fundamental physics**
12.30-14.00 - **Lunch**
14:00-14:20 – Mario Gai **Gravitation Astrometric Measurement Experiment**
14:20-14:40 – Giuseppe Cimo **Accurate astrometry for Planetary Radio Interferometry and Doppler Experiment**
14:40-15:00 - Paulo Freire **GAIA and Millisecond Pulsars**
15:00-15:20 - **Poster session**
15.20-15.50 - **Coffee Break**
15:50-16:35 - Orfeu Bertolami **Underlying principles of our current theories**
16:35-17:20 - Fernando de Felice **The observer's space-time puzzle**
17:20-18:20 - **Splinter Meetings**

20:00 - **Conference Dinner**

Epistemology Implications of current theories of the Universe

Thursday, 9th June

09:30-10:15 - Orfeu Bertolami **What if ... General Relativity is not the Theory?**
10:15-11:15 - **Open general discussion**
11.15-11.45 - **Coffee Break**
11:45-12:15 - **Summary of the meeting**
12:15-12:30 - **Concluding remarks**
12:30 - **End of the meeting**

POSTERS

Ioana Sotuela

UCM-UAM/MDSCC-INSA

The contribution of X/Ka-band VLBI to multi-wavelength studies of the Celestial Frame

Taehyun Jung

Korea Astronomy Space science Institute (KASI)

Korean VLBI Network (KVN) and its recent activities