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ASTROMETRY WITH GROUND BASED OPTICAL TELESCOPES

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Abstract. Astrometry with ground based optical telescopes is a newly developed theme in the SYRTE department of the Paris observatory. It recovers some activities like: - the observation of the WMAP probe with optical telescopes for the future astrometric monitoring of GAIA, - the realization of an ecliptic catalog of quasars (using the CFHT images), - the link between radio and optical positions of quasars. In the case of WMAP we will detail more particularly the observations made with the ESO 2.2 m telescope and with the 105 cm telescope of the Pic du Midi. Our goal is to be able to obtain the position of GAIA on its orbit with an uncertainty of 150m in position and 2.5 mm/s in velocity. For that purpose, the telescope of the Pic du Midi could be used as a main observing station when GAIA will be launch. We will give the firsts results obtain for the astrometric reduction of the images of WMAP obtain with these two telescopes. We also present the CFHT-LS project. We will use the images of the Very Wide survey to realize an astrometric catalog of quasars. The goal of this project is to obtain the position of quasars with an uncertainty around 10mas up to the 25th magnitude. It will permit to densify the GAIA catalog.

1 Introduction

In the domain of astrometry, SYRTE is involved in the realization of the International Celestial Reference Frame (ICRF) which is necessary to know with optimal precision the location of all the bodies in the Universe. One of the tasks consists in establishing the coordinates of quasars as accurately as possible. These quasars are assumed to provide fixed (quasi-inertial) directions in space, which make it possible to determine the coordinates of moving objects: stars in galactic rotation, planets and asteroids rotating around the sun etc... Because of the increasing number of sources in the catalogues of quasars, it is necessary to make their intercomparison as well as the analysis of the extremely accurate observation data obtained by very long baseline interferometry (VLBI) in the radio domain, or by CCD images in the focal plan of large telescopes at optical wavelengths. Another research theme is the link between the International Celestial Reference System and the dynamical system represented by the trajectories of the mobile bodies in the solar system. At SYRTE, the analysis of lunar laser ranging data, of pulsar chronometry, and the use of optical observations lead to the determination of this link.

2 Astrometry with optical telescopes at SYRTE-OP

Since january 2007 a team of SYRTE-OP is particularly involved in the field of astrometry with ground based optical telescopes. Some points of interest are currently under development: - The realization of an ecliptic catalogue of quasars, - the link between the dynamical reference system and the ICRF through the observation of asteroids, - the link between radio and optical positions of quasars and their photometric vs astrometric variability, - the observation of WMAP to prepare the GAIA mission. The two next subsections show the telescopes and softwares used to obtain images and analyse them.

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2.1 The telescopes

Up to now three ground based optical telescopes have been used to obtain images both for quasars and WMAP. The larger one is the 3.6m optical/infrared telescope TCFH (Telescope Canada France Hawaii). The observatory is located atop the summit of Mauna Kea, a 4200 meter dormant volcano, located on the island of Hawaii (USA). The MEGACAM camera, a set of 36 CCD, was used together with the telescope (see 4.1). The second one is the 2.2m Telescope of the European Southern Observatory at La Silla (Chile). It has been in operation since 1984. The telescope is a Ritchey-Chretien design mounted on an equatorial fork mount. The telescope is at a geographical location of 70d44'4"543 W 29d15'15"433 S and an altitude of 2335 metres. It was used with the Wide Field Imager (WFI), a focal reducer-type camera at the Cassegrain focus and with a field of view of 34'x33'. The last and small one is the 1.05m Telescope of the Pic du Midi (France). It is located in the south-west of France by 42d56'10".9N, 00d08'32".6E and 2877m in altitude. In 1963 that telescope was used in collaboration with the Na tional Aeronautics and Space Administration (NASA) to prepare the Apollo missions for moon landing.

2.2 Tools for reduction/analysis of observations

Softwares used to reduce and analyse images can be devided in two sets. The home made softwares have been built for astrometric reduction, linking of independant CCD of a large camera (MEGACAM, WFI...), quasars identification, differential astrometry. The automatization of these softwares is scheduled for large catalogue realization. The other set is made of known softwares (IRAF or TERAPIX suite, see 4.3). Sextractor, Scamp, Swarp were used to obtain a file with the postion of the detected object on the CCD and to control that the equatorial coordinates obtain by the home made softwares were consistent.

3 WMAP for GAIA

3.1 Preparing the GAIA mission

The requirements, due to astrometric reasons, about the position and velocity of the spacecraft on its orbit are very stringent. It has been shown (Perryman 2005, Mignard 2005) that the uncertainty must be, at most, 150m (20mas) and 2.5 mm/s (1mas/h) respectively. The classic Doppler and ranging techniques can only deliver 6 km and 8 mm/s. To achieve that high level of requirements the only usable technique is the Ground Based Optical Tracking (GBOT). GAIA's location roundabout the L2 Lagrange point is approximately 1.5 million km from the Earth, facing roughly opposite of the sun. It's visual magnitude would be approximately 18 (this value can be off by a hugge amounts). In order to prepare the GBOT of GAIA, the Wilkinson Microwave Anisotropy Probe (WMAP) has been choosen. That probe is also located around the L2 Lagrange point and its magnitude (roughly 19) is very near from the expected magnitude of GAIA. WMAP is then a reasonable model for the brightness and observability of GAIA. The precise astrometric position of WMAP has been provided by Dale Fink, Navigator of WMAP Spacecraft Control Team at NASA.

3.2 ESO 2.2m + WFI

Sebastien Bouquillon (SYRTE-OP), Ricky Smart (INAF/OATo, Torino) and Alexandre Andrei (Observatorio Nacional, Rio de Janeiro) have used the 2.2m telescope of the European Southern Observatory at La Silla, Chile, to take several images of NASA's WMAP satellite in its orbit. Sextractor (Terapix) or Daophot (IRAF) have been used to obtain the (x,y) positions of the sources on the CCD. The standard deviation of the difference between the computed and the observed positions gives the best available information about the standard deviation of WMAP. Results obtained with three independant softwares are given here:

	Home made	TERAPIX	IRAF
Right asc.	70.1mas	70.5mas	69.7mas
Dec.	80.8mas	77.0mas	72.2mas

3.3 T105 Pic du Midi (France)

The astrometric reduction has been done with the same three independant softwares that for the ESO CCD. A plate solution was determined with a second order polynomial in x and y leading to the following residuals:

Time of observ.	sigma(alpha)	sigma(delta)
23h05m33s	64mas	48mas
23h09m00s	65mas	61mas
23h12m25s	65mas	57mas

The results obtain were compared with the theoretical ephemeride supplied by Dale Fink. Moreover the brightness of WMAP has been calibrated with respect to the UCAC2 reference stars (UCAC2 stars are not photometric standards). The results are as follows:

Time of observ.	diff(alpha)	diff(delta)	mag(+/-1sigma)
23h05m33s	21.104”	3.234”	18.620(+/-0.249)
23h09m00s	21.297”	3.141”	18.661(+/-0.257)
23h12m25s	21.530”	3.231”	18.757(+/-0.251)

The difference between the observed position and the ephemeride is relatively large but quite constant. This can be due to the ephemeride itself (constant offset), to the inaccuracy of the position of the telescope (10m), to the time synchronisation of the Pic du Midi (0.1s) or to other effect...

The fluctuation of the magnitude can be explained by the ambient condtions (extremely difficult conditions with light diffusion through clouds, moon's age of 11 and bad seeing). The rapid changes in object brightness due to varying illumination of spacecraft must also be taken into account.

4 The CFHT-LS

Canada and France have joined a large fraction of their dark and grey telescope time for a large project, the Canada-France-Hawaii Telescope Legacy Survey (CFHTLS). More than 450 nights over 5 years will be devoted to the survey using the wide field imager MegaPrime equipped with MegaCam. The three main entities serving the Canadian and French communities are 1) the CFHT for the data acquisition, pre-processing and calibration, 2) the Canadian Astronomy Data Centre (CADC) for all activities related to the archiving and release of the various data products to the communities, and 3) Terapix (based in Paris) for the data ressampling and stacking, fine astrometric calibration, and source catalogs generation.

4.1 TCFH-MEGAPRIME/MEGACAM

The telescope itself has been described above (see 2.1). MegaPrime is the wide-field optical imaging facility at CFHT. The wide-field imager, MegaCam (built by CEA, France), consists of 36 2048 x 4612 pixel CCDs (a total of 340 megapixels), covering a full 1 degree x 1 degree field-of-view with a resolution of 0.187 arcsecond per pixel to properly sample the 0.7 arcsecond median seeing offered by the CFHT at Mauna Kea. The new prime focus upper end includes an image stabilization unit and a guide/autofocus unit with two independent guide CCD detectors.

4.2 CADC

The Canadian Astronomy Data Centre (CADC) serves the Canadian and French communities for all activities related to the archiving and release of the various data products.

4.3 Terapix

TERAPIX (Traitement Elementaire, Reduction et Analyse des PIXels de megacam) is an astronomical data reduction centre dedicated to the processing of extremely large data flows from digital sky surveys. TERAPIX is located at IAP (Institut d'Astrophysique de Paris). Its primary tasks are: - to develop image processing and pipeline software for MegaCam; - to develop and provide tools for handling of large CCD images; - to operate the final reduction pipeline to produce calibrated images and catalogues of MegaCam images over the next 5 years; - to provide technical assistance and computing facilities for MegaCam and WIRCam users.

4.4 The three surveys

The Canadian and French scientific agencies have decided to set up the CFHTLS observational program. It consists of three observational programs: - The CFHT-LS "very wide": 1300 square degrees over the ecliptic area and focussed on the Trans-Neptunian and Kuiper Belt observations. - The CFHT-LS "wide": covering 170 square degrees over three large fields located at high galactic latitude, in "dust-free" areas of the sky. The wide survey will be focussed on large-scale structure of the Universe, cosmological weak lensing, clusters of galaxies, quasars as well as stellar proper motions in the Galaxy. - The CFHT-LS "deep": covering four uncorrelated 1 square degree patches (i.e., one MegaCam field) in "dust-free" areas of the sky. The deep survey will be optimised for the detection of light-curve measurements of Type Ia supernovae and the study of very high redshift galaxies.

5 Observations with TCFH

Six of the QSO quasars densest (on average 25 QSOs up to R=21) SDSS DR5 regions were selected for two band optimum photometry observation using MEGACAM to obtain the largest at this date, statistically significant and coherent sample of the magnitude, size, and astrophysics of the host galaxies of the quasars. The DR5 regions guarantee a high number of galaxy and stellar comparison objects. In parallel it furnishes ugriz magnitudes for all and spectral information for many ones. Two fields in the ecliptic plane complied the density threshold and will additionally enable one to obtain a direct comparison between the ICRF and the dynamical system represented by field asteroids. Bright cusps on the GAIA QSOs PSF will give rise to astrometric jitter. This program will give practical templates and constraints for the definition of the QSO Initial Catalogue for GAIA. The detailed luminosity profile of the host galaxy so obtained can be combined to the DR5 data in order to contribut e to the understanding of their morphology, star formation history and dust distribution. The observations of the semester 08A obtained at TCFH are up to now under investigation.

Other observations in the public domain will be used to transfer the astrometric precision of the GAIA catalogue to faint objetcs, up to the 25th magnitude, in the ecliptic fields, with the help of the CFHT-LS VW survey. In return it will permit us to densify the GAIA catalogue.

6 Conclusion

Since january 2007 a team of SYRTE-OP is particularly involved in the field of astrometry with ground based optical telescopes

In the frame of the GBOT-GAIA, first observations of WMAP have been done with the 2.2m ESO and 1.05m Pic du Midi telescopes. For that late telescope we propose to use it as a main observing station when GAIA will be launched. Preliminary results show that it is possible to obtain the postion of WMAP with the uncertainty of the UCAC2 stars. Hence when the GAIA early-catalogue will be accessible to the GBOT community the uncertainty about the GAIA position could be better than 20 mas. It will permit to reach the very stringent requirements of the GAIA mission.

Observations of the CFHTLS will be used to transfert the astrometric precision of the GAIA catalog for faint objects, up to the 25th magnitude, in the ecliptic fields, with the help of the Very Wide survey. In return it will permit us to densify the GAIA catalog.

References

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