Title
=====

Astrometry for 21st Century Astronomy

Details
=======

Focus Meeting at XXXI IAU General Assembly, 2021, Busan, Rep. of Korea

Coordination Division: A Fundamental Astronomy
Supporting Divisions: F Planetary Systems and Astrobiology
                G Stars and Stellar Physics
                H Interstellar Matter and Local Universe

SOC chairs
==========

Anthony Brown, Leiden, Netherlands
Aletha de Witt, Hartebeesthoek, South Africa
Christopher Jacobs, JPL, USA
David Hobbs, Lund, Sweden

SOC members
===========

Name (country, expertise)

Chiara Battistini (Germany, 4MOST)
Leanne Guy (USA, LSST)
Pierre Kervella (France, VLTI)
Sergei Klioner (Germany, Gaia)
Chao Liu (China, LAMOST/CSST)
Cecilia Mateu (Uruguay, Milky Way Science)
Timo Prusti (Netherlands, Gaia)
Maria Rioja (Australia/Spain, VLBI/SKA)
Federica Spoto (USA, Solar system/Gaia)
Yoshiyuki Yamada (Japan, Small-JASMINE)
Kathy Vieira (Chile, Astrometry)

Scientific Justification
========================

Key topics

- Review of modern astrometry and its science applications
- Astrometry science highlights, including from Gaia DR2 and Gaia EDR3
- Future ground and space-based astrometric surveys
- Dense and accurate reference frames to optimize the science return from

extremely large telescopes and large sky surveys
- Astrometric techniques; opportunities for cross-fertilization
- Synergies between astrometric, photometric, and spectroscopic surveys

Abstract

High accuracy astrometry has made spectacular progress over the past decade
thanks to developments in VLBI techniques, the appearance on the scene of the
GRAVITY instrument, and the giant step taken with the Gaia mission in the
quality and depth of its astrometric survey. High accuracy astrometric data is
now indispensable across astronomy disciplines and in solar system science.
With this focus meeting we wish to highlight the scientific progress based on
these astrometric data and bring together the various astrometry and sky
survey communities; to learn from each other, explore opportunities for
coordination and map out the synergies between astrometry and other techniques
and surveys, aiming to maximize the scientific outputs. The IAU GA is the
natural venue to bring the communities together and the timing is right, a
year after the appearance of the early part of the third Gaia release, three
years after the adoption of the ICRF-3, five years into GRAVITY operations,
and on the eve of the era of LSST and extremely large telescopes.

Rationale

The data from the Gaia mission have enabled spectacular progress in the
characterization and understanding of the complex structure and formation
history of the Milky Way, mostly driven by the availability of distance and
kinematic information over unprecedented volumes of Galactic phase space. The
astrometric data from the Gaia mission have impacted all astronomy disciplines
as evidenced by over 2000 papers having appeared between April 2018 and
December 2019 that use Gaia DR2 astrometry in one way or another. In the field
of stellar astrophysics it is now natural for astronomers to look up parallax
and proper motion information on any star in the Gaia catalogue; the field of
white dwarfs is profiting from a dramatically expanded knowledge of these
objects in the volume around the sun, leading to the first unequivocal
evidence of the crystallization of their interiors; the field of exoplanets
has profited from a much more detailed understanding of the planet host stars,
while the studies of proto-planetary disks are free of the distance
uncertainties from the past. Current and future Gaia data releases hold the
promise of closing in on a per cent level measurement of the Hubble Constant,
while at the other end of the astronomical spectrum studies of asteroids in
the solar system will be revolutionized by the availability of hundreds of
thousands of extremely accurate orbits.

In parallel the GRAVITY instrument at the VLT has revolutionized narrow field
astrometry, producing measurement accuracies at the tens of micro-arcsecond
level which led to the definitive measurement of the distance to the Galactic
centre, high accuracy studies of the motions of stars around the central black
hole, and the first direct detection of an exoplanet by optical

interferometry. The VLBI astrometry community has continued to refine their techniques and routinely deliver parallax and proper motion measurements at accuracy levels equal to or better than Gaia. Both techniques allow to probe regions throughout the Milky Way disk that are obscured to optical astrometry, such as star forming clouds, the spiral arms, and the Galactic centre region.

This breadth of applications of astrometric data from Gaia, GRAVITY, and VLBI illustrates the extent to which 21st century astronomical research is underpinned by the access to highly accurate positions, parallaxes, and proper motions for a dense network of sources out to faint magnitudes, as well as high astrometric precision over small and possibly obscured or crowded fields. The increase in the quality and quantity of astrometric data is set to continue over the next decade, with further Gaia data releases based on more observations and better calibrations as well as astrometry from large sky surveys such as the LSST. Several planned space missions will also deliver precise source positions (in some cases at several epochs) which can be combined with other astrometric survey data to deliver accurate long time baseline proper motions; examples are Euclid, WFIRST, and the Chinese Space Station Telescope (CSST, 15000 square deg high spatial resolution photometric and slitless spectroscopic survey). In the longer term further advances in astrometry can be expected from missions such as Small-JASMINE and GaiaNIR and from the new possibilities offered by the SKA.

With this focus meeting we aim to bring together the producers and users of high accuracy astrometric data in order to reflect on recent scientific successes founded on astrometry; to present and exchange ideas on proposals for future astrometric surveys; to learn about astrometric techniques across different wavelength ranges and instrument concepts; and to have a discussion on the synergies between the different astrometric techniques and surveys. For example the dense optical reference frame provided by Gaia will feed into the astrometric calibration of large sky surveys and the calibration of high precision relative astrometry conducted with future extremely large telescopes, while also serving the precise pointing needs of these telescopes.

In particular we aim at bringing together the various astrometry communities (Gaia, VLBI, ground-based surveys, specialized astrometric instruments) which often work in relative isolation from each other. The complementarity of the various techniques and surveys can be leveraged through coordinated strategies in defining future directions for astrometry. Looking beyond just astrometry it is important to also consider the power of the combination of astrometric, photometric, and spectroscopic data. We will thus also take the opportunity to discuss the synergies between astrometric and other surveys, such as the large spectroscopic surveys WEAVE, 4MOST, and SDSS-V starting up over the next few years, and the imaging/photometric surveys that are ongoing (SkyMapper) or starting soon (LSST).

The IAU General Assembly is the natural venue to hold this focus meeting as we can take advantage of the presence of members from the various astrometric, survey, and science communities and bring them together. The timing of the meeting is favourable as it takes place one year after the release of the

early part of the third Gaia data release (Gaia EDR3), which will be the most recent update on the Gaia astrometry, and the community will have had time to digest the results. The ICRF-3, the first mutli-frequency radio reference frame, will have been available for three years. The GRAVITY instrument will have been in operation for five years and the first data from the LSST should be in hand, while large spectroscopic surveys that complement the astrometric data will have started or are about to start. The first light for the E-ELT will be only a few years away and the timing is opportune to discuss how the dense optical reference frame provided by Gaia and ground based surveys can be leveraged to maximize the science exploitation of the E-ELT and other extremely large telescopes.

Programme outline

We plan a two day meeting divided into the six blocks listed below, focusing on each of the key topics. We foresee 15-20 minute talks, including time for discussion. In addition a 30 minute review talk will be scheduled in which an overview of the field of modern astrometry and its science applications will be given.

We list the names of potential speakers for the various topics. Note however that we intend to invite only one or two speakers per topic and leave the rest of the slots open to contributed talks, where we want to especially encourage young colleagues to present their work and ideas.

Astrometry science highlights (2 blocks)
- Modern astrometry review talk
- Gaia DR2 and Gaia EDR3
- GRAVITY
- VLBI
- AO-assisted narrow field astrometry
- Ground based surveys

Potential speakers: L. Lindegren, U. Bastian (review talk), R. Beaton (distance scale), T. Antoja (Gaia Milky Way science)

Astrometric techniques
- Global astrometry, lessons learned from Gaia
- Narrow-field high precision astrometry (GRAVITY, Keck/AO, ELT, etc)
- Astrometry from ground based surveys (LSST, DES, Pan-Starrs, etc)
- VLBI astrometry

Potential speakers: M. Reid, M. Honma, N. Sakai (VLBI), O. Pful, S. Lacour, A. Mérand (GRAVITY/VLTI)

Dense and accurate reference frames to optimize the science return from extremely large telescopes and large sky surveys
- Astrometry with extremely large telescopes
- Optical-radio synergies

- Space-ground synergies

Potential speakers: E. Tolstoy (E-ELT astrometry), F. Mignard (multi-wavelength reference frames)

Future astrometric surveys
- GaiaNIR, JASMINE, WFIRST, Theia/MAP, LSST, ...
- VLBI, SKA, ...
- Research and development needs for achieving sub-microarcsecond astrometry
- Opportunities for coordination
- Synergies with other space missions: Euclid, CSST, WFIRST, ...

Potential speakers: R. Dodson (SKA), N. Gouda (JASMINE), K. Lind, G. Kordopatis (4MOST), N. Zacharias (ground-based astrometry)

Synergy between astrometric, photometric, and spectroscopic surveys
- Astrometry and photometry (LSST, SkyMapper, DES, ...)
- Astrometry and spectroscopy (WEAVE, 4MOST, SDSS-V, ...)

Potential speakers: A. Queiroz, F. Anders