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DIVISION G
COMMISSION 26

DOUBLE AND MULTIPLE STARS
ÉTOILES DOUBLES ET MULTIPLES

PRESIDENT Brian D. Mason
VICE-PRESIDENT Yuri Balega
PAST PRESIDENT Jose Docobo
ORGANIZING COMMITTEE Frédéric Arenou, Marco Scardia, Vakhtang Tamazian, Theo ten Brummelaar, Patricia Lampens, Bo Reipurth, Andrei Tokovinin

TRIENNIAL REPORT 2012-2015

1. Introduction

This report covers the workings of Commission 26 over the triennial period 2012-2015 and is the last report of the Commission. Included are reports from Working Groups and the Commission 26 Circular; all of which will be continuing in Commission G1 (*Binary and Multiple Stars*). Also included is a report of the Splinter Meeting of Commissions 26, 42 & G1, submitted observatory reports and a history of Commission 26.

2. Working Groups

Commission 26 has two working groups whose reports are presented below. The first working group is a recent addition from Commission 30 (Radial Velocities) while the second continues work done under the aegis of the Commission since 1964.

2.1. *Catalog of Orbital Elements of Spectroscopic Binary Systems - Dimitri Pourbaix*

Over the past three years, in the absence of active contributions from most of the authors of spectroscopic orbits, the objective of the WG was to upload some big batches of orbits resulting from surveys rather than uploading many papers with one or two orbits. The primary selection of these contributors was made easier thanks to the work by H. Levato and his team (Bibliographic catalogue of stellar radial velocities). By combining their compilation with the present content of *9^{th} Catalogue of Spectroscopic Binary Orbits*† (hereafter, SB9), it is indeed possible to identify the added value for SB9 (in terms of systems) resulting from the uploading of a given paper. Some screening was nevertheless necessary as Levato's team does not make the distinction between a planetary orbit and a stellar one (only the latter goes to SB9).

† available online at `sb9.astro.ulb.ac.be`

This selection resulted in the addition of 35 papers, with 367 new systems and 431 new orbits. On average, 10.5 orbits were added per paper, to be compared with an average of 3.8 orbits per paper over the 2009–2012 period. In August 2015, SB9 contains 3479 systems with 4297 orbits. For 2507 of these systems, the radial velocities of some of or all of their orbits are available.

Despite significant contributions by the authors of orbits, they do use SB9 and acknowledge it! Over the first 8 months of 2015, more than 6300 orbital plots were retrieved from the website. That number corresponds to the fruitful queries only. Over the same period, more than 200 copies of the SB9 data files were downloaded as well. As of August 2015, 250 papers quote the SB9 paper according to ADS.

By assuming the completeness of Levato's compilation, it is possible to guess the completeness of SB9 in terms of systems. Such an estimate is crucial for those interested in inferring some statistical behaviour of binaries based upon the SB9 content. An analysis based upon the identifiers yields a completeness of 60% (August 2015). However, the multiplication of the identifiers makes this task even more difficult. The 60% should thus be seen as a lower bound. An estimate, based upon the coordinates, should provide an upper bound as, in dense regions such as clusters, the matching of sources could be too optimistic.

On a purely administrative side, it is worth noting that the SB9 WG moved from Commission 30 (Radial Velocities) to Commission 26 (Double and Multiple Stars) after the IAU 2012 GA. Even though the initiative of establishing SB9 arose at the 2000 GA within the radial velocity commission, it had become clear over the years that the scientific content of SB9 was more suited to a double star audience than to some pure spectroscopists interested in obtaining the most precise and accurate radial velocities. With the agreement of the former presidents of both commissions, the WG was migrated. The move was totally transparent to the users.

2.2. *Maintenance of the Visual Double Star Database - Brian Mason*

After more than a half-century of dedicated double star cataloging and observing, and after publication of the IDS, at the 1964 meeting of Commission 26 (van de Kamp, P. 1966, IAUTB **12**, 267) during the 12th General Assembly in Hamburg, Lick Observatory Director A.E. Whitford informed the Commission that Lick no longer wished the responsibility of maintaining the Catalog. An offer by Kai Strand, then early in his tenure as Scientific Director of the U.S. Naval Observatory (hereafter, USNO), offered for the USNO to be the official Double Star Center. This was voted on and approved by the Commission, and this meeting, 26 August 1964, is the inception date of the Washington Double Star Catalog (hereafter, WDS), which therefore is celebrating its 50^{th} year during this triennium.

2.2.1. *Washington Double Star Catalog*

As of 15 June 2015, the WDS contains 1,276,937 mean positions of 132,600 pairs†. Of these, 15.5% (n = 20,558) are deemed physical due to orbit computation, common proper motion or common parallax or other means; 3.5% (n = 4694) are counted as optical due to a linear motion solution, mutually exclusive proper motion or parallax or other means; 0.6% (n = 677) are believed to be not real but are retained (and indicated as such) to avoid future queries or ambiguities, and the majority (80.4%) have unknown physical/optical status. See Figure 1.

† available online at `ad.usno.navy.mil/wds/wds.html`

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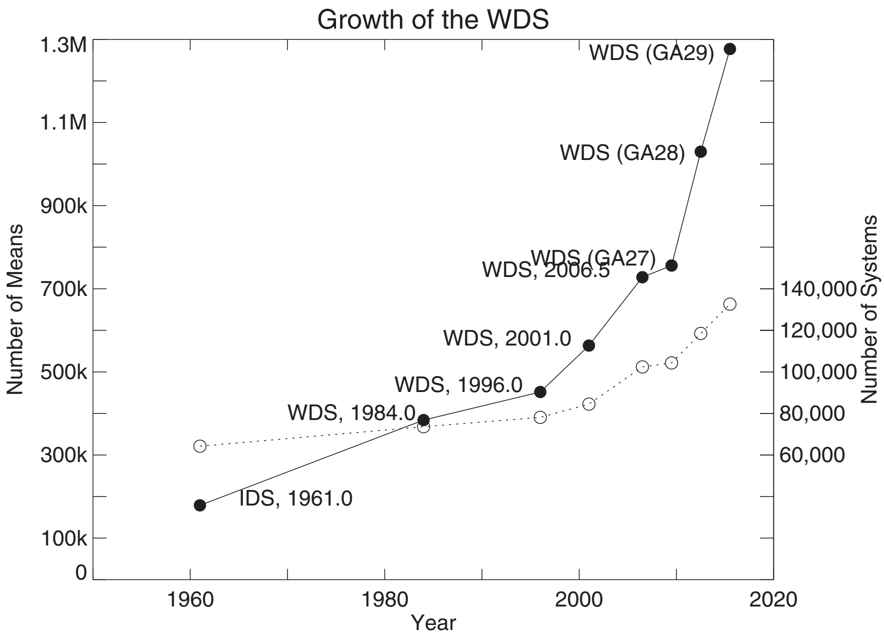

Figure 1. The figure illustrates the growth of the WDS vs. time. Filled circles and the solid line with the axis at left gives the number of mean positions while open circles and the dashed line with the axis at right gives the total number of systems. Points indicate the inception of the WDS (Jeffers *et al.* 1963, Pub. of the Lick Observatory **21**), previous major releases in 1984 (Worley & & Douglass 1984, U.S. Naval Observatory, Washington), 1996 (Worley & Douglass 1997, A&AS **125**, 523), 2001, (Mason *et al.* 2001, AJ **122**, 3466), 2006.5 (Mason & Hartkopf 2007, The Second USNO Double Star CD, U.S. Naval Observatory, Washington), 2009 (IAU-GA XXVII), 2012 (IAU-GA XXVIII) and 2015 (IAU-GA XXIX).

While 80.4% is far from desirable, it is much lower than that of earlier editions of the WDS (e.g., 98.3% in WDS, 2001.0). Over the past several years the focus has been on measuring neglected pairs which are either unconfirmed or have not been measured in many years. Matching WDS systems with astrometric catalogs (e.g., Hartkopf *et al.* 2013, AJ **146**, 76) and changes in observing strategies by many institutions has made a significant difference in measures per system. For example, the mean number of measures per system for each of the eight points in Figure 1 are: 2.78, 5.22, 5.78, 6.67, 7.11, 7.25, 8.69 and 9.63. Future contributions will include matching URAT and other large astrometric catalogs with the WDS.

2.2.2. *Orbit & Linear Catalogs*

The *6th Catalog of Orbits of Visual Binary Stars*† contains the 2634 graded best orbits of 2529 resolved pairs. It also contains 24 orbits of interferometric pairs. These are assumed to be of very high quality but as the solutions are of the interferometric observables of Baseline and Visibility rather than the Separation and Position Angle of other resolved systems, so they cannot be evaluated with conventional methodologies. As most current optical interferometers are more than 2-element this problem should diminish with time. The catalog also contains 523 astrometric orbits of unresolved pairs whose orbits are based on period variations in the astrometric position. Most of these are from Hipparcos. Finally, the catalog contains 43 partial solutions where at least one

† available online at `ad.usno.navy.mil/wds/orb6.html`

of the seven Campbell elements is not determined. These are of dubious value save as an indicator of likely physicality.

The Catalog of Rectilinear Elements† contains 1483 solutions to resolved pairs. While they could be long period, highly eccentric orbits, they are assumed to be optical due to differential proper motion until proven otherwise.

Both of these catalogs have shown considerable growth (orbit: 34%, linear: 27%) since the last major catalog release (2006.5). However many solutions may be premature, so **an** answer is not necessarily **the** answer.

2.2.3. *Other Catalogs and Services*

• The *4th Catalog of Interferometric Measurements of Binary Stars* provides online high resolution measurements of known double stars as well as single star detections.

• The *3rd Photometric Magnitude Difference Catalog* contains reliable differential magnitude information.

• We also provide all available published data to specific systems on demand and can prepare custom observing lists to your telescope, instrument/technique and location.

We are in debt to Geoff Douglass for his work on the WDS database and his leadership in the speckle program at the USNO. The WDS and USNO speckle program were conceived and nurtured by Charles Worley. While the list of contributors is too great to enumerate everyone by name a few who do not appear in the reference list for these contributions improving the database include: Francisco Manuel Rica Romero, Richard Jaworski, Brian Skiff, Bruce MacEvoy, Gianluca Sordiglioni, Wilfried Knapp, Chris Thueman and Friedrich Damm.

3. Information Circulars - Jose Docobo

The Information Circular was started in 1954 by Paul Muller of the Observatoire de Strasbourg, France, and was known as the “Commission 26 Information Circular.” Publication of the Circular was taken over in 1983 by Paul Couteau of the Observatoire de Nice and in 1993 by J.A. Docobo, who proposed J.F. Ling as co-editor. Both are members of the Observatorio Astronomico “Ramon Maria Aller‡,” of the Universidade de Santiago de Compostela, Spain.

The lists of new binaries and orbital elements which have traditionally comprised the Circulars were recently supplemented by bibliographies of published binary star papers, obituaries and general information. Both paper and electronic versions of the Circular are published by Drs. Docobo and Ling. Contributions to this most worthwhile publication should be sent to the editors¶.

Issues of the IAUDS are available online at the Commission 26‖ and G1 Webpage††.

4. XXIX GA Splinter Session - Brian Mason

At IAU-GA XXIX there were no scheduled Commission meetings, however, there was opportunity to schedule a “Splinter” Session which could serve in this capacity. The commission application of what would become the new commission G1 (“Binary and Multiple Stars”) was submitted by the Presidents of Commission 26 (“Double and Multiple Stars”

† available online at `ad.usno.navy.mil/wds/lin1.html`
‡ `http://www.usc.es/astro`
¶ `joseangel.docobo@usc.es` or `josefinaf.ling@usc.es`, respectively.
‖ `http://ad.usno.navy.mil/wds/dsl/Comm26/circular_intro.html`
†† `http://ad.usno.navy.mil/wds/bsl/G1_pub_ic.html`

- Brian Mason) and 42 (“Binary Stars” - Mercedes Richards) as well as individuals who were members of both Commissions (Andrej Prša and Virginia Trimble). As such, it seemed appropriate for the Business & Scientific Sessions of the Commissions to be held jointly to aid in the identification of synergistic activities. This was held the afternoon of 11 August 2015.

The reports of Commissions 42 and G1 are elsewhere in Transaction B. That of the Commission 26 Business Meeting is below immediately followed by a list of presentations in the scientific portion of the splinter meeting. Most of these are available online†.

4.1. *Commission 26 Business Session*

Members in attendance : Christine Allen, Alan Batten, David Brown, David Dunham, Theo ten Brummelaar, Francis Fekel, Brian Mason, Gene Milone, Dimitri Pourbaix, Andrej Prša, Bo Reipurth, Virginia Trimble, Gerard van Belle and Shay Zucker.

We are saddened to report the passing of the following Commission 26 members: Jean Dommanget (1924-2014), Paul Couteau (1923-2014), Alexei Kiselev (1922-2013), Chris Morbey (1942-2012) and J. Murray Fletcher (1940-2012).

For the forseeable future, the *Double Star Libary*‡, the webpage of Commission 26, will be maintained.

The following resolution was passed unanimously.

4.1.1. *On the Epoch of Relative Double Star Measures*

Historically, double star observations made preferentially with long-focus instruments have been published at the equator and equinox for the epoch of observation. Any correction for precession or proper motion was made later, typically by an orbit computer.

Recently, there have been a plethora of “data mining” operations from astrometric catalogs to extract double star data. However, the positions of stars in these catalogs are typically given for a special equinox, such as J2000, rather than for the date of observation. For these data to be properly treated the position angle of the double star measure needs to be corrected for precession so that it refers to the epoch of observation via a well known (Fletcher 1931, MNRAS **92**, 119; Aitken 1963, *The Binary Stars*, Dover, New York; Heintz 1978, *Double Stars*, Reidel, Boston) relation:

$$\Delta\theta = +0.0056\ sin\ \alpha\ sec\ \delta\ (t - t_0).$$

The need for this correction is best demonstrated in Figure 2 (adapted from Wycoff *et al.* 2006, AJ **132**, 50).

Therefore,

Recognizing the contributions that can be made in double star astrometry from astrometric catalogs it is recommended that when the angle of position is given to a common epoch it be precessed to the epoch of observation.

4.2. *Scientific Session*

- History of Commission 42 (Virginia Trimble)
- The Final Kepler EB Catalog (Andrej Prša)
- The Visual Double Star Catalogs (Brian Mason, see §2.2)
- Coordinate System Issues in Binary Star Computations (George Kaplan)

† `http://ad.usno.navy.mil/wds/bsl/splinter.html`
‡ see `ad.usno.navy.mil/wds/dsl.html`

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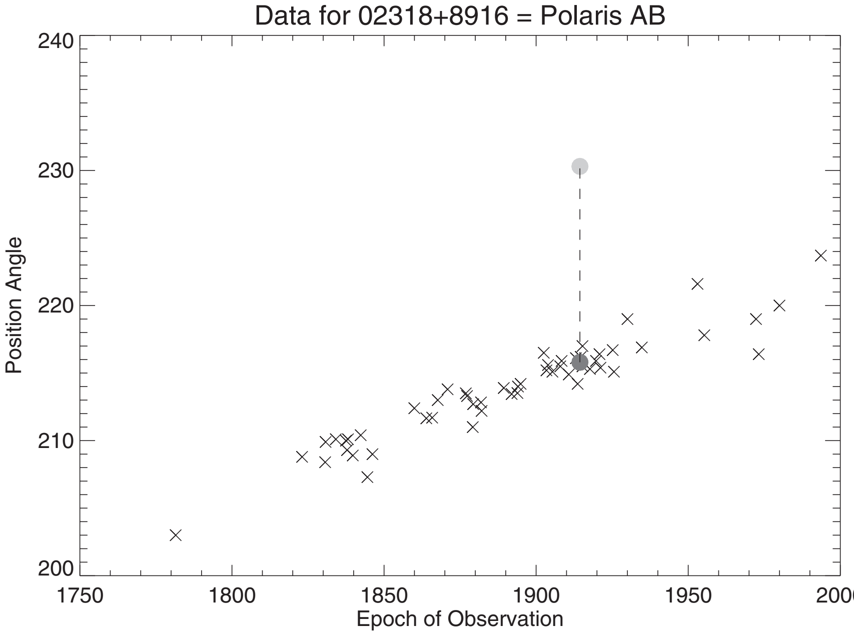

Figure 2. Position angle vs. time for measures of the double star Polaris AB (WDS 02318+8916). Classical double star measures — all referred to their mean equator and equinox of observation — are represented with crosses. The calculated position angle from the Second Greenwich Catalog (Dyson 1935, *Second Greenwich Cat. of stars for 1925.0*, London: H.M. Stationary Off.) precessed to J2000.0 is given as a light filled circle. Precessing the position back to equator and equinox of the observation (dark filled circle) changes the position angle significantly, to where it matches contemporaneous measures quite well.

- Direct Distance Estimation Applied to Eclipsing Binaries in Star Clusters: Case Study of DS And in NGC 752 (Eugene Milone)
- Θ^1 Ori B: a quintuple (sextuple?) system less than 30,000 years old (Christine Allen)
- Two bright eclipsing binaries in the Orion Trapezium (BM and V1016 Ori) (Rafael Costero)
- Advances in spectroscopy and implications for stellar research (David Soderblom)
- Binary Stars and the CHARA Array (Theo ten Brummelaar)
- The 9th catalogue of orbits of spectroscopic binaries (Dimitri Pourbaix, see §2.1)
- Gaia non single stars (Dimitri Pourbaix)
- Double Star work being done with the DCT, the NPOI and the end of Commission 54 (Gerard van Belle)

A thorough summary of the Scientific Session is not possible here but many of the presentations as well as pictures of the meeting are available online at the Commission G1 webpage†.

5. Observatory Reports

5.1. *Institute of Astronomy RAS - Oleg Malkov*

The Binary star DataBase (BDB) is the world's principal database of binary and multiple systems of all observational types. The ongoing mission of BDB is to provide a

† see ad.usno.navy.mil/wds/bsl/splinter.html

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comprehensive and easy-to-use database of fundamental information for known (cataloged) objects in multiple stellar systems. BDB contains data on physical and positional parameters of 240,000 components of 130,000 systems of multiplicity 2 and more, belonging to various observational types: visual, interferometric, spectroscopic, eclipsing, X-ray, etc. The current database is the result of a systematic integration of data from tens of heterogeneous sources of data — astronomical catalogs and surveys. BDB can be queried by star identifier, coordinates, and other parameters. Further information about BDB content and functionality is available at the BDB website† and in various publications (e.g., Kaygorodov *et al.* 2012, Baltic Astronomy **21**, 309; Kovaleva *et al.* 2015, Astronomy and Computing **11**, 119). A new version of BDB, with improved interface, drastically improved performance and enhanced visualization results, will be available in September 2015.

Due to necessity of a unified and consistent system for designation of objects, the Binary Star DataBase (BSDB) designation scheme for identifying objects in double and multiple systems was developed. The BSDB scheme covers all types of observational data. Three classes of objects (system, pair, component) introduced within the BSDB nomenclature provide correct links between objects and data, which is especially important for complex multiple stellar systems.

The principles underlying BSDB identifier compilation satisfy the "IAU Specifications concerning designations for astronomical radiation sources outside the solar system". In July 2015 BSDB acronym was accepted by the IAU Registry and entered into the Reference Dictionary of Nomenclature of Celestial Objects.

5.2. *Cerro Tololo Interamerican Observatory - Andrei Tokovinin*

A general renaissance of binary-star astronomy propelled by new observational techniques (e.g., AO, Lucky Imaging, interferometry, precise RVs) and stimulated by work on exo-planets around nearby stars has resulted in better statistics (cf. Duchéne & Kraus 2013, ARA&A **51**, 269) and, therefore, in a progress towards understanding formation of multiple stars.

Work done at CTIO:

• Multiplicity of a large sample of solar-type stars in the 67-pc volume has been characterized statistically (2014 AJ **147**, 86 & 2014 AJ **147**, 87). This involved new observations at Gemini-S (AO, companions in wide binaries and resolution of Hipparcos astrometric binaries), search of wide companions in 2MASS and their confirmation, speckle interferometry at SOAR (subsystems, astrometric binaries), and a large survey with Robo-AO (subsystems in secondary components and discoveries of distant companions). As a result, the fraction of hierarchical systems is established, 13±1%, and a statistical model is developed to represent population of binary and higher-order multiples in the field.

• In collaboration with Mason & Hartkopf, USNO and Horch, SCSU, a large number of speckle-interferometry measurements were done at SOAR — the almost unique source of such data in the southern hemisphere. The total number of measures now exceeds 5000 resulting in the improvement of several hundred orbits and the first resolutions of many systems or subsystems.

• A unique quadruple system HD 91962 with a 3-tier hierarchy and almost co-planar orbits (2015 AJ **149**, 195) was studied using RVs and speckle which gives insight into the formation mechanisms of multiple stars.

† `http://bdb.inasan.ru`

5.3. *Institute of Astronomy, Cambridge, UK - Robert Argyle*

A series of micrometric observations of visual double stars was made with the 67cm refractor at the Johannesburg Observatory in 2008, 2010 and 2013. The 525 measures of 213 pairs separated by less than 5″ were published (AN **336**, 387, 2015) along with revised orbits for four southern binary stars. The results for pairs wider than 5″ can be found in the references below.

The writer continued to edit the Double Star Section Circulars of the Webb Society. During the period 2012 Sep 30 to 2015 Aug 31, three circulars were published (Nos 21, 22 and 23) in which position angle and separation values are presented for 7361 measures of 2575 wide double stars and common proper motion pairs by seven observers (Skiff, Courtot, Argyle, Ahad, Jenkinson, Napier-Munn and Tute)†.

5.4. *OARMA Team - Jose Docobo*

(*a*) Articles
  (*a*) Journal articles.
    i. Malkov *et al.* 2012, *Dynamical masses of a selected sample of orbital binaries*, A&A **546**, A69
    ii. Docobo & Andrade 2013, *Dynamical and physical properties of 22 binaries discovered by W.S. Finsen*, *MNRAS* **428**, 321
    iii. Melikian *et al.* 2013, *Spectral observations of flare stars in the neighborhood of the Sun*, Ap **56**, 8
    iv. Docobo *et al.* 2014, *An analytic algorithm to calculate the inclination, ascending node, and semimajor axis of spectroscopic binary orbits using a single speckle measurement and the parallax*, AstBu **69**, 461
    v. Campo & Docobo 2014, *Analytical study of a four-body configuration in exoplanet scenarios*, AstL **40**, 737
    vi. Docobo *et al.* 2014, *The three-dimensional orbit and physical properties of the binary COU2031 (WDS 04464+4221, HIP 22196, HD 30090)*, *MNRAS* **444**, 3641
    vii. Tamazian & Malkov 2014, *Catalog of Binary UV Ceti Type Flare Stars*, AcA **64**, 359
    viii. Docobo & Andrade 2015, *On the Hipparcos Accuracy Using Binary Stars as a Calibration Tool*, AJ **149**, 45
  (*b*) Articles in Meeting Proceedings
    i. Docobo 2012, *The R.M. Aller Astronomical Observatory Research on Double and Multiple Stars: Highlights and Projects*, POBeo **91**, 155
    ii. Docobo *et al.* 2013, *Analysis of a Daytime Fireball Witnessed on August 10, 2012 over the Iberian Peninsula*, 2013, LPI **44**, 1053
    iii. Docobo *et al.* 2014, *Observation of Three Twilight Bolides in August, 2013 from Galicia, NW of Spain*, LPI **45**, 1820
    iv. Andrade & Docobo 2015, *The Dynamical Evolution of the Multiple Stellar System α Gem*, ASPC **496**, 94
(*b*) Observation runs (Director: J. A. Docobo).
  (*a*) Special Astrophysical Observatory (Russia): Speckle interferometry
  (*b*) Byurakan Astrophysical Observatory (Armenia): Speckle interferometry
  (*c*) Montsec Observatory (Catalonia, Spain): Photometry
  (*d*) Observatory of the Institute of Astronomy, Cambridge (United Kingdom): Radial velocities
(*c*) Publications edited

† see `www.webbsociety.org/double-stars/double-star-section-circulars`.

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(*a*) Information Circular of Comm. 26 (IAUDS), Numbers: 178-186, Editors: Docobo & Ling

(*d*) Orbits and Notes published in the IAUDS.

(*a*) Orbits

i. Circular 178 (Oct-2012): 02382+4604 = A 1278 : Docobo & Campo; 02396−1152 = FIN 312 : Docobo & Andrade; 04093−2025 = RST 2333 : Docobo & Campo; 04163−6057 = GLE 1 : Docobo & Ling; 15313−3349 = HWE 78 AC : Ling; 15457+5040 = HU 657 : Docobo & Ling; 16057−3252 = SEE 264 AB : Docobo & Ling; 17591+3228 = HU 1185 : Docobo & Campo; 19035−6845 = FIN 357 : Docobo & Andrade; 19411+1349 = KUI 93 : Docobo & Ling; 20154+6412 = MLR 60 AB : Docobo & Andrade

ii. Circular 179 (Feb-2013): 04263+3443 = HU 609 : Docobo & Ling; 08585+3548 = COU 1897 : Docobo & Tamazian; 09100−2845 = B 179 : Docobo & Campo; 12409+2708 = COU 596 : Docobo & Ling; 12533+4246 = COU 1579 : Docobo & Ling; 20599+4016 = COU 2431Aa1,2 : Docobo & Campo I y II; 23078+6338 = HU 994 : Docobo & Campo

iii. Circular 180 (Jun-2013): 10269+1931 = COU 292 : Docobo & Ling; 15041−0653 = HO 391 AB : Ling; 15420+4203 = COU 1445 : Docobo & Ling; 16584+3943 = COU 1289 : Docobo & Ling; 20527+4607 = A 750 AB : Docobo & Campo; 22493+1517 = HDS 3241 : Docobo & Campo; 23357−2729 = SEE 492 : Docobo & Campo

iv. Circular 181 (Oct-2013): 00126−1142 = RST 3343 : Docobo & Ling; 13007+5622 = BU 1082 : Docobo & Campo; 19264+4928 = YSC 134 : Docobo *et al.*; 19027+4307 = YSC 13 : Docobo *et al.*; 19089+3404 = COU 1462 : Docobo & Ling; 20151+3742 = COU 2416 : Docobo & Ling; 20374+7536 = HEI 7 : Docobo & Andrade; 21597+4907 = HU 774 : Docobo & Andrade

v. Circular 182 (Feb-2014): 00546+1911 = STT 20 AB : Docobo & Ling; 00593−0040 = A 1902 : Docobo & Ling; 01497−1414 = HU 422 : Docobo & Ling; 13175−0041 = FIN 350 : Docobo *et al.* I y II; 18434−5546 = B 398 : Docobo & Campo

vi. Circular 183 (Jun-2014): 06298−5014 = HDO 195 CD : Docobo & Ling; 12415−4858 = HJ 4539 : Docobo & Campo; 12597−0349 = CHR 39 Aa,Ab : Docobo & Campo

vii. Circular 184 (Oct-2014): 02543+5246 = LAB 1Aa,Ab : Docobo & Campo; 07346+3153 = STF 1110AB : Docobo *et al.*

viii. Circular 185 (Feb-2015): 02366+1227 = MCA 7 : Docobo *et al.*; 02434−6643 = FIN 333 : Docobo *et al.*; 03244−1539 = A 2909 : Docobo *et al.*; 08507+1800 = A 2473 : Docobo *et al.*; 09128−6055 = HDO 207 : Docobo *et al.*; 11532−1540 = A 2579 : Docobo *et al.*; 13535−3540 = HWE 28 AB : Docobo & Ling; 17366+0723 = A 1156 : Docobo & Ling; 17375+2419 = CHR 63 : Docobo *et al.*; 22408−0333 = KUI 114 : Docobo *et al.*

ix. Circular 186 (Jun-2015): 10373−4814 = SEE 119 : Docobo & Campo; 12429+0516 = A 1602 : Docobo & Ling; 13123−5955 = SEE 170 : Docobo & Campo

(*b*) Notes : In Memoriam of Dr. Paul Couteau, Circular n. 184

(*e*) Other publications

(*a*) J.F. Ling has published a translation to Spanish of P. Couteau's book: *Esos astronomos locos por el cielo o la historia de la observacion de las estrellas dobles*, 2013 (*b*) J. A. Docobo has published a biography of R. M. Aller in Galician: *Ramon Maria Aller Ulloa*, Astronomo e Matematico, 2014

(*f*) Direction of PhD Dissertations on binaries: Prof. J. A. Docobo is directing the doctoral dissertations of:

(*a*) Pedro Pablo Campo Diaz (*Binaries and Exoplanets*)

(*b*) Jorge Gomez Crespo (*Binary Observation Techniques*)

(*c*) Ahmad Abushattal (*Spectroscopic Binaries*)

(*g*) Maintenance of the OARMA Catalog of Orbits and Ephemerides of Visual Double Stars (OARMAC): The Catalog is currently maintained by Docobo *et al.* and contains 2225 orbits of 1817 systems

(*h*) Research Project: Study of astrophysical and dynamical properties of double and multiple stars on the basis of speckle interferometry, photometry and spectroscopy (AYA2011-26429). Funded by the Spanish Ministry of Science and Innovation. Principal Investigator: J. A. Docobo. Developed from January 2012 to December 2014.

5.5. *Konkoly Observatory - Laszlo Szabados*

Binarity of 15 bright classical Cepheids (14 in our Galaxy, 1 in the LMC) have been pointed out. There is still serious deficiency of known binaries among the faint Cepheids.

The related publications are as follows:

- Szabados & Nehez 2012, *Binarity among Cepheids in the Magellanic Clouds*, *MNRAS* **426**, 3148
- Szabados *et al.* 2012, *Discovery of the spectroscopic binary nature of the Cepheids X Puppis and XX Sagittarii*, *MNRAS* **426**, 3154
- Szabados *et al.* 2013, *Discovery of the spectroscopic binary nature of six southern Cepheids*, *MNRAS* **430**, 2018
- Szabados *et al.* 2013, *Discovery of spectroscopic binary nature of three bright southern Cepheids*, *MNRAS* **434**, 870
- Szabados *et al.* 2014, *Discovery of the spectroscopic binary nature of the classical Cepheids FN Aql and V1344 Aql*, *MNRAS* **442**, 3155
- Kovtyukh *et al.* 2015, *Discovery of blue companions to two southern Cepheids: WW Car and FN Vel*, *MNRAS* **448**, 3567

5.6. *PISCO Group - Luigi Pansecchi*

- M. Scardia and L. Pansecchi, INAF-Osservatorio Astronomico di Brera, Merate, Italy
- J.-L. Prieur, CNRS-Toulouse University, France
- E. Aristidi, Université de Nice-Sophia Antipolis, France
- R.W. Argyle, Cambridge Observatory, U.K.

During the period 2012-2014, we continued our speckle observation program of visual binaries with PISCO at the 1.02-m Zeiss Telescope of the INAF - Osservatorio Astronomico di Brera in Merate. The total number of measurements made since 01 January 2004 now exceeds 3570. At the same time, we also collaborated with the Observatoire de la Côte d'Azur (OCA), France, with respect to the transfer of PISCO to their station on the Plateau de Calern (1270-m a.s.l.), in the light of existing agreements. This transfer is justified by the continuous deterioration of the sky over Merate, mainly due to the increasing light pollution. At Calern, PISCO will be mounted on the telescope "Epsilon", one of the old, twin telescopes of 1-m aperture composing the infrared interferometer "SOIRDETE" long since unused due to the conclusion of the original project. Both the

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telescopes are being restored and modernized and provided with new, high-quality optics. The transfer of PISCO to Calerne is expected to take place in summer 2015.

Publications in refereed journals in 2012-2014

• Prieur *et al.* 2012, *Speckle observations with PISCO in Merate. XI. Astrometric measurements of visual binaries in 2010*, *MNRAS* **422**, 1057

• Scardia *et al.* 2013, *Speckle observations with PISCO in Merate. XII. Astrometric measurements of visual binaries in 2011*, MNRAS **434**, 2803

• Prieur *et al.* 2014, *Speckle observations with PISCO in Merate. XIII. Astrometric measurements of visual binaries in 2012 and new orbits for ADS 10786BC, 12144, 12515, 16314 and 16539*, AN **335**, 817

Other publications in 2012-2014

• Scardia *et al.* 2013, *Speckle interferometry with PISCO in Merate and prospects for the future*, at International Workshop on "Binaries inside and outside the local interstellar bubble", held 10-11 February 2011, in Santiago de Compostela (Spain)

• Scardia *et al.* 2012, *Le tavelographe PISCO à Merate: Règultats et perspectives*, CA-PAS 2012, Onet le Château, France

• Scardia *et al.* 2012, *Orbital elements of ADS 11170, and 16314*, IAU Commission 26 Circulaire d'Information n° 176

• Scardia *et al.* 2012, *Orbital elements of ADS 2377, 9182, 12144, 12515, 14748, and 16539*, IAU Commission 26 Circulaire d'Information n° 177

• Scardia *et al.* 2012, *Orbital elements of ADS 8739, and 12880*, IAU Commission 26 Circulaire d'Information n° 178

• Scardia *et al.* 2013, *Orbital elements of ADS 9626*, IAU Commission 26 Circulaire d'Information n° 179

• Scardia *et al.* 2013, *Orbital elements of ADS 7775, 9578, and 14412*, IAU Commission 26 Circulaire d'Information n° 180

• Scardia *et al.* 2013, *Orbital elements of ADS 713, 9378, 9836(I), 9836(II), and BSO 13AB*, IAU Commission 26 Circulaire d'Information n° 181

• Scardia *et al.* 2014, *Orbital elements of ADS 16345, 16393, and HU 1335*, IAU Commission 26 Circulaire d'Information n° 182

• Scardia *et al.* 2014, *Orbital elements of ADS 1097, 8954, 11186, and 16463*, IAU Commission 26 Circulaire d'Information n° 183

5.7. *Universidad Nacional Autónoma de México - Christine Allen*

• Monroy-Rodríguez & Allen 2014, *The End of the MACHO Era, Revisited: New Limits on MACHO Masses from Halo Wide Binaries*, ApJ **790**, 159

• Allen & Monroy-Rodríguez 2014, *An Improved Catalog of Halo Wide Binary Candidates*, *ApJ* **790**, 158

• Olivares *et al.* 2013, *Kinematics of the Orion Trapezium based on diffracto-astrometry and historical data*, AJ **146**, 106

• Olivares *et al.* 2014, *Diffracto-Astrometry Measurements: Kinematics of the Orion Trapezium*, RevMexA&A (Serie de Conferencias) **43**, 83

• Ruelas-Mayorga *et al.* 2014, *Diffracto-Astrometry Measurements: Accuracy of the Measuring Algorithm*, RevMexA&A (Serie de Conferencias) **43**, 79

• Sánchez *et al.* 2014, *Diffracto-Astrometry measurements: the Technique*, RevMexA&A (Serie de Conferencias) **43**, 75

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• Allen & Costero 2015, *The dynamical future of the mini-cluster* Θ^1 *Ori B*, AJ (*in press*)

5.8. *Observatorio Astronómico Nacional - Valeri Orlov*

• Orlov *et al.* 2014, *Speckle Interferometry at the Observatorio Astronómico Nacional. V.*, RevMexA&A **50**, 151

• Orlov *et al.* 2015, *Speckle Interferometry at the Observatorio Astronómico Nacional. VI.*, RevMexA&A **51**, 65

5.9. *Central Astronomical Observatory of the RAS Pulkovo - Natalia Shakht*

• Izmailov *et al.* 2015, *Photographic observations of visual double stars at Pulkovo: digitization, measurement and calibration*, AstL (*accepted*)

• Kiyaeva *et al.* 2015, *Dynamical and astrometrical investigations of binary stars with automated 26-inch refractor in Pulkovo. Last results.*, Report on IV International Meeting on Binary and Multiple Stars, 18-20 Sept 2015, Vilanova, Spain

• Shakht *et al.* 2013, *Estimation of stellar masses on the basis of observations of double stars at Pulkovo observatory*, Massive Stars from α to Ω, 10-14 June 2013, Rhodes, Greece

• Kiselev *et al.* 2014, *Pulkovo Catalog of Relative Positions and Motions of Visual Double and Multiple Stars from Photographic Observations with the 26-inch Refractor in 1960-2007*, ARep **58**, 78

• Shakht *et al.* 2015, *Estimation of dynamic paremeters and boundaries of the habitable zones of selected stars of Pulkovo program*, Solar System Research (*accepted*)

• Izmailov & Roshchina 2015, *Astrometric observations of visual-double stars using 26-inch refractor during 2007-2014 at Pulkovo*, AstBu (*accepted*)

5.10. *Koninklijke Sterrenwacht van België - Patricia Lampens*

5.10.1. *Spectroscopic binary systems, several of which contain a pulsating star*

Detailed studies of the following spectroscopic systems have been reported:

• BR CMi, a close binary system with an evolved companion showing emission in the Balmerlines;

• HD 25558, two Slowly Pulsating B-type stars forming a double-lined binary with an orbital period of about 9 years;

• HD 51844, a δ Scuti pulsating star in a non-eclipsing eccentric binary with an orbital period of about 33 days observed by the CoRoT satellite. Its light curve shows strong tidal effects at periastron passage;

• the long-period binary system PG 1104+243 consisting of a subdwarf B-type star and a main-sequence star with an orbital period of about 753 days and a mass ratio of 0.637±0.015;

• We initiated a spectroscopic study concerning a sample of candidate hybrid pulsating stars with ultra-precise light curves from the Kepler mission with the aim to determine their atmospheric parameters (spectral classification, T_{eff}, *log g* & *v sin i*) and rate of multiplicity. New binary and triple systems have been detected among the sample of candidate hybrid stars whose radial velocities are being monitored with the HERMES spectrograph mounted at the Mercator telescope, La Palma. First results indicate a possible multiplicity fraction of almost 20% (i.e. 7/38 targets).

Publications:

• Vos *et al.* 2012, *The orbits of subdwarf B + main-sequence binaries. I. The sdB+G0 system PG 1104+243*, A&A **548**, A6

• Sódor *et al.* 2014, *Extensive study of HD 25558, a long-period double-lined binary with two SPB components*, *MNRAS* **438**, 3535

• Lampens *et al.* 2015, *Investigation of the binary fraction among candidate A-F type hybrid stars detected by Kepler*, In: Proc. of the "Space Photometry Revolution", CoRoT Symp. 3 - KASC 7 Joint Meeting, 7-11 July 2014, Toulouse (France), EPJ Web of Conferences

• Harmanec *et al.* 2015, *Properties and nature of Be stars. 30. Reliable physical properties of a semi-detached B9.5e+G8III binary BR CMi = HD 61273 compared to those of other well studied semi-detached emission-line binaries*, A&A **573**, 107

• Hareter *et al.* 2014, *HD 51844: An Am delta Scuti in a binary showing periastron brightening*, A&A **567**, 124

5.10.2. *Observations of visual systems*

• High-angular resolution observations collected with the ESO 3.6m telescope equipped with the ADONIS camera and broad-band near-infrared filters were used to obtained relative positions and differential magnitudes (in the JHK-passbands) for 36 nearby southern orbital binaries.

• The measurements of relative positions of 129 visual double and multiple systems performed by E. Van Dessel during the years 1969-1974 were summarized and published, enabling their exploitation for future orbit computations. In the summer of 1968, 64 measurements of 38 different systems were collected with the 50cm equatorial refractor of the Observatoire de Nice. From 1969 till 1974, 295 measurements of 91 systems were collected with the 45-cm equatorial refractor of the Royal Observatory of Belgium (ROB).

• Measurements of the relative positions as well as differential magnitudes between the components of visual double stars have been acquired using a CCD camera of type SBIG ST-10XMe equipping small telescopes with various apertures (up to 25cm) at the remote Humain station of the ROB. We used the programme Astrometrica for the reduction of the CCD frames. This concerns 139 measurements of 133 different systems.

Publications:

• Lampens *et al.* 2013, *Relative astrometry and near-infrared differential photometry of nearby southern orbital binaries with adaptive optics*, AN **334**, 237

• Lampens & Van Cauteren *Mesures d'étoiles doubles visuelles obtenues á l'observatoire de Beersel (BHO) puis á la station astronomique de Humain (HOACS) de 2007 á 2010*, Observations et Travaux - Revue de la Société Astronomique de France, *submitted*

• Lampens *et al.* 2012, *Mesures d'étoiles doubles visuelles obtenues avec la lunette de 50 cm de l'Observatoire de Nice (1968) et avec la lunette de 45 cm de l'Observatoire royal de Belgique de 1969 á 1974*, Observations et Travaux, No. 79, 17

5.10.3. *Eclipsing systems and red giant stars*

Publication:

• Frandsen *et al.* 2013, *Detached Eclipsing Binaries and Heartbeat Stars in the Kepler field*, in: Setting a New Standard in the Analysis of Binary Stars, Eds. K. Pavlovski, A. Tkachenko and G. Torres. EAS Publications Series **64**, 393-394

5.10.4. *Varia*

Publication:

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• Lampens, P. 2014, Obituary : JEAN C.A. DOMMANGET (1924-2014), Information Circular No. 184, IAU Comm. 26

5.11. *U.S. Naval Observatory - Brian Mason*

The primary observational double star resource of the USNO remains our venerable 26″ refractor. Over the triennium, a total of 7367 observations were made resulting in 3607 mean positions and helping lead to 81 orbits appearing in the Commission 26 Circular. The primary observing program remains that of neglected doubles which we define as those which have either never been confirmed or those without a published double star measure in the past decade. These are listed in Mason *et al.* 2012, AJ **143**, 124; Mason *et al.* 2013, AJ **146**, 56 and Hartkopf & Mason 2015, AJ **150**, 136.

We are in the midst of mechanical upgrades to the telescope and our camera. Over the triennium, the inital modification from microscope objectives to simple lenses using a design provided by A. Tokovinin (CTIO) has increased the throughput of the instrument. The telescope itself has been upgraded with new digital encoders, software and a finder camera such that all observing now takes place in a warm room twenty feet north of the dome. This work was accomplished due to the efforts of the USNO Intrument Shop (Gary Wieder, Chris Killian, Eric Ferguson), members of the Optical Reference Frame Division (Norbert Zacharias, Charlie Finch, William Hartkopf, Brian Mason), contractors (Greg Bredthauer, Ted Rafferty), and summer intern Tai Ragan. Progress continues with an additional simple lens option being designed to reach the diffraction limit (200 mas) once the pointing model is fully optimized.

Despite its status as a double star workhorse, there remain many pairs which are inaccessible. For these, active collaborative relationships have been established giving us access to other pairs. Those include Andrei Tokovinin (see §5.2 above — 2012, AJ **143**, 42; 2014, AJ **147**, 123; 2015, 2015, AJ **149**, 195; AJ **150**, 50) for southern hemisphere and close pairs, Douglas Gies *et al.* (2014, AJ **147**, 40; 2015, AJ **148**, 48) for work on massive stars and binaries with the Fine Guidance Sensors of the Hubble Space Telescope, Lewis Roberts, Reed Riddle *et al.* (2015, ApJ **799**, 4; 2015 AJ **149**, 118; 2015 AJ **149**, 144; 2015 AJ **150**, 130) for work on systems hosting exoplanets and other pairs whose magnitude difference exceeds the detection capability of interferometry, Nancy Evans *et al.* (2013 AJ **146**, 93) examining Cepheid Variables with companions, Howard Bond et al. (arXiv:1510.00485) examining large magnitude difference systems with the Hubble Space telescope, Chris Farrington, Theo ten Brummelaar et al. (2014 AJ **148**, 48) examining very close pairs with the CHARA Array and Bob Zavala, Haley Hurowitz, Jonathan Hurowitz and Elizabeth Griffin examining very close pairs with the NPOI. All of these collaborations are active and continue. In addition, we have collaborated on one-off projects with Hugh Harris *et al.* (2013, ApJ **779**, 21) on the binary white dwarf LHS 3236, Maggie Turnbull *et al.* (2012, PASP **124**, 418) on a possible star shade space mission and Matthew Muterspaugh (2015, AJ **150**, 140) on the eclipse timing of α Comae.

6. History of Commission 26 - Josefina Ling

While the focus of this section is the history of Commission 26 it also serves as a blueprint for some of the future work of Commission G1.

The International Astronomical Union (IAU) was born in the Constitutive Assembly of the International Research Council (ICR), which took place from July 18 to 28 in 1919, in the Palace Academy located in Brussels. As a result of a long process that started before

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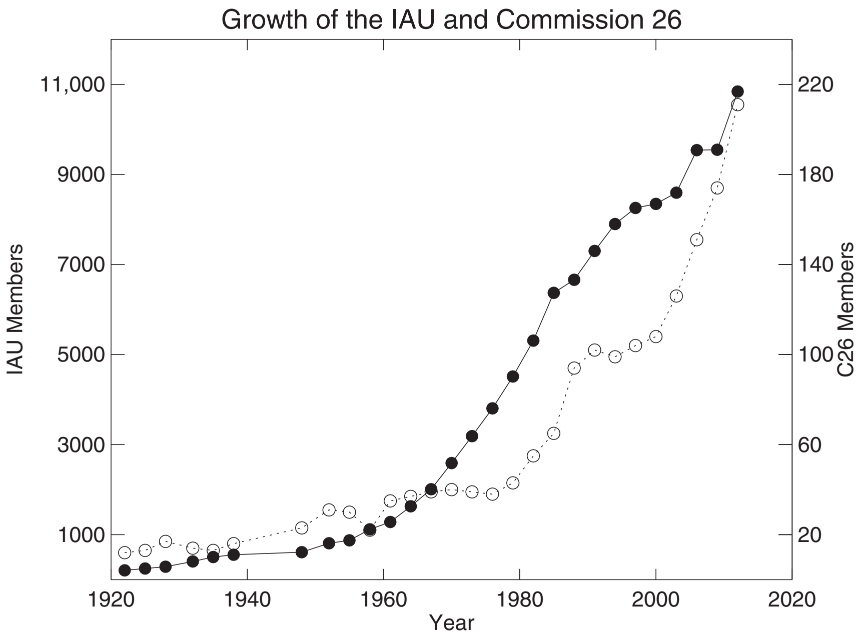

Figure 3. The growth of Commission 26 membership (open circles), compared with that of the IAU as a whole (filled circles). Note the scales: the IAU scale is 50× that of C26. Small-number statistics are a factor here but it appears that during the first four decades of the IAU, double stars constituted a fairly significant area of research within the IAU. On the other hand, the years 1960-1976 and 1991-1997 were periods of stagnation for the commission, which at one point was in danger of dissolution. The last two decades saw significant growth, with membership relative to the IAU approaching numbers not seen in over 40 years.

World War I, it aimed to encourage collaboration among those involved in astronomy worldwide. The ICR established the possibility of creating International Associations for specific branches of science in which the IAU was the first one. The statutes were approved on July 28, 1919 thereby being the official date of its birth, precisely during the closing act of the Constitutive Assembly of the ICR. The purpose of the IAU was, and still is, to promote and safeguard astronomy in all its aspects through international cooperation.

The first statutes of the IAU stipulated that a General Assembly (GA) was to meet as a rule every 3 years and that it must be structured in 32 Standing Committees (actual Commissions) specialized in different fields of astronomy. Double stars (DS) were represented from the outset through one of these pioneering commissions, number 26, under the name of Double Stars. The number of commissions has not always remained constant. Over time, some have disappeared, new ones have surfaced and some were merged or absorbed. Commission 26 — despite being one of the smallest in terms of the number of members, but not in terms of its scientific production — survived until 2015, though not without some moments of peril towards its existence. It has experienced only small changes of name in two of the 29 General Assemblies of the IAU, in which Commission 26 has always been present. In the 9^{th} GA, held in Dublin in 1955, the resolution to add the word "visual" to the title of the Commission was approved. Similarly, in the 18^{th} GA, held in Patras (1982), the name was again modified to "Double and Multiple Stars" which it maintained until 2015. Figure 3 shows the membership growth of the IAU and Commission 26 and Table 1 lists the officers of the Commission.

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In the first General Assembly held in Rome in 1922, the IAU only had 207 members from the 19 allied or neutral countries from World War I, thereby excluding the "enemy countries". In this GA, Commission 26 held its first Commission Meeting with R.G. Aitken as the first president and with a total of nine members. Already important decisions were made, which then took the form of resolutions adopted by the IAU. They were the main pillars that over time would adjust to the needs of the time, or expanding to new areas of discussions during subsequent meetings. Most of the rules and job habits used by the researchers in the binary stars field are the results of collection throughout working sessions of Commission 26 conducted within the GA of the IAU; from the 1^{st} in Rome in 1922, to the 29^{th} in Hawaii in 2015.

What follows is a brief overview of the main activities of Commission 26 during its 96 years of existence.

6.1. *Creation of Central Office - Resolution 1, 1^{st} GA*

One of the first actions of Commission 26 was to create an office that could serve as a communication link between the astronomers dedicated to double stars. At first it focused on the observers in order to provide indications of observation programs and a list of stars to measure. Subsequently and until the 1950s it also served to boost the exchange of information during difficult times, for example during World War II it provided recommendations on the inclusion of stars with special features, with perturbed motions, triple and multiple systems, data for orbit determination and statistical analysis, or to contrast theoretical studies. The main office was located in the Northern Hemisphere at Lick Observatory and was operational until the 1960s, when it transferred its responsibilities to the USNO. In the Southern Hemisphere, Union Observatory (Johannesburg, South Africa) was considered a sub-office but ended its work shortly before the disappearance of the observatory itself in 1971. Another noteworthy place was the European Center for Double Stars, created in 1972 at Nice Observatory, but, unfortunately, it was dismantled at the end of April 2015 after the death of its founder Paul Couteau.

6.2. *Adoption of definitions, classifications and formulas*

The prerogative of the IAU is the implementation of homogeneous and consistent criteria and standards for the development of scientific work in astronomy. This is done through resolutions or agreements adopted by their Commissions. In this regard, Commission 26 has been in charge of managing the study of double stars in relation to:

- the astronomical parameters of observation: the position angle (θ) and the angular separation (ρ), its symbols, units and reference systems (*Resolution 2, 1^{st} GA, Rome 1922*),
- the orbital elements for different types of orbits, establishing its definitions, a single system (*Resolution 1, 1^{st} GA, Rome 1922*), the Thiele-Innes constants, the criteria for direct and retrograde motions, for the position of the ascending node, etc.,
- the different formulation on binary criteria based on various parameters, determination of preliminary periods, different mass-luminosity relations, formulas to calculate the mass of double and multiple systems, etc.,
- questions of terminology: *dynamic parallax* in its forms of "*orbital*" and "*non-orbital*", photometric parameters like the *brightness parameter or specific magnitude* amongst others, and
- the introduction of new variables such as the *apparent relative speed.*

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Term	President	Vice President	Secretary	Organizing Committee
	Commission 26 Officers			
1919-1922	Robert Aitken			
1922-1925	Robert Aitken			
1925-1928	Robert Aitken			
1928-1932	Ejnar Hertzsprung		George van Biesbroeck	
1932-1935	Ejnar Hertzsprung			
1935-1938	Ejnar Hertzsprung			
1938-1948				
1948-1952	Willem van den Bos R. Aitken, honorary			
1952-1955	Paul Muller			
1955-1958	Paul Muller		Peter van de Kamp	
1958-1961	Peter van de Kamp		Sarah Lippincott	
1961-1964	Peter van de Kamp	Richard Woolley	Sarah Lippincott	1
1964-1967	Kai Strand	Paul Couteau	Jean Dommanget	2
1967-1970	Paul Couteau	Jean Dommanget	Sarah Lippincott	3
1970-1973	Jean Dommanget	Sarah Lippincott	Otto Franz	4
1973-1976	Sarah Lippincott	Paul Muller	Otto Franz	5
1976-1979	Paul Muller	Otto Franz		6
1979-1982	Otto Franz	Mario Fracastoro	Jean Dommanget	7
1982-1985	Mario Fracastoro	Karl Rakos		8
1985-1988	Karl Rakos	Harold McAlister		9
1988-1991	Harold McAlister	Helmut Abt		10
1991-1994	Helmut Abt	Charles Worley		11
1994-1997	Charles Worley	Hans Zinnecker		12
1997-2000	Hans Zinnecker	Colin Scarfe		13
2000-2003	Colin Scarfe	William Hartkopf		14
2003-2006	William Hartkopf	Christine Allen		15
2006-2009	Christine Allen	Jose Docobo		16
2009-2012	Jose Docobo	Brian Mason		17
2012-2015	Brian Mason	Yuri Balega		18

1 : O. Eggen, P. Muller, K. Strand, W. van den Bos
2 : O. Eggen, P. Muller, J. Dommanget, P. Kulikovsky, R. Petrie
3 : O. Eggen, P. Muller, K. Strand, P. Kulikovsky, P. van de Kamp
4 : P. Couteau, P. Muller, K. Strand, A. Deutsch, P. van de Kamp
5 : P. Couteau, A. Batten, K. Strand, A. Deutsch, J. Dommanget, O. Franz
6 : R. Harrington, A. Batten, M. Fracastoro, C. Worley, S. Lippincott
7 : R. Harrington, P. Kulikovsky, P. Muller, C. Worley, A. Poveda, C. Scarfe
8 : J. Dommanget, O. Franz, W. Heintz, H. McAlister, A. Poveda, C. Scarfe
9 : J. Dommanget, H. Abt, P. Couteau, M. Fracastoro, R. Harrington, A. Kiselyov
10 : P. Bernacca, E. van Dessel, P. Couteau, R. Harrington, A. Kiselyev, K. Rakos
11 : P. Bernacca, E. van Dessel, H. Zinnecker, Y. Balega, F. Fekel, C. Scarfe
12 : C. Allen, W. Hartkopf, A. Tokovinin, Y. Balega, F. Fekel, C. Scarfe
13 : C. Allen, W. Hartkopf, A. Tokovinin, J. Armstrong, R. Mathieu, M. Valtonen
14 : F. Fekel, P. Lampens, J. Ling, J. Armstrong, R. Mathieu, M. Valtonen
15 : F. Fekel, P. Lampens, J. Ling, J. Davis, E. Oblak, T. Oswalt
16 : Y. Balega, B. Mason, D. Pourbaix, C. Scarfe, J. Davis, E. Oblak, T. Oswalt
17 : Y. Balega, D. Pourbaix, C. Scarfe, F. Arenou, M. Scardia, V. Tamazian
18 : F. Arenou, M. Scardia, V. Tamazian, T. ten Brummelaar, P. Lampens, B. Reipurth, A. Tokovinin

6.3. *Observation Programs*

Historically, the members of Commission 26 have approached several subjects in relation to their main field of work: the observation of binary stars. The organization and distribution of observation runs implies the need for information and guidance on different issues, technical as well as methodological, policy and/or organizational. Some of these issues for the principal measurement types in regard to these stars are enumerated below.

6.4. *Measurements of Relative Positions*

The observations that provide insight into the motion of the components of double stars in their apparent orbits are treated, historically, with different observation techniques which have served to identify systems with different orbital properties, such as periods, separations, etc. These include, but are not limited to: micrometry, photography, inter-

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ferometry, television amplification, CCDs, occultation, adaptive optics and space-based observations.

6.4.1. *Work Methodology*

In order to standardize as much as possible of the observations, Commission 26 has been responsible for arbitrating the main methodological lines of work. Sometimes they even have been adopted as resolutions of the IAU. For example:

- For a given period, limit the number of observation nights. (*Resolution 3, 1st GA, Rome 1922*)
- Avoid continuous repetition of observations of known pairs whose relative or common proper motions are small, or even the total abandonment of certain pairs.
- The observations must be as accurate as possible, improving, in particular, the observation of slow pairs by using photographic techniques.
- Measure rapid pairs to check and calculate new orbits.
- Draw up lists of stars to study systematic errors (*Resolution 4, 1st GA Rome 1922*) ratified ten years later at the *4th GA Cambridge, USA 1932*) — and to check the angular resolution and the personal equation, both in visual measures as in the photographic ones.
- Organize and disseminate binary measurement runs of a certain interest: high proper motion binary stars composed by a red star and a white dwarf, neglected pairs, stars to be observed by lunar occultations, etc.

6.4.2. *Standards in Publication*

Until the mid-20th Century, in response to Resolution 7 of the 1st GA (Rome 1922), the values for each double star measurement that had to be present in the publication were: the epoch (with 3 decimals), the position angle, the angular distance and estimated visibility (by a weight assigned), the telescope aperture, the power of the ocular, the estimated size, a reference number and the equatorial coordinates of the star. It was also necessary to unify the coordinates of the stars, adopting the same equinox, and sort them according to right ascension. The results had to be presented in one publication, rather than scattered in several. The requirement to give at least two cross-identifications of the pair was later added to avoid confusion, as well as the difference of magnitudes and the quadrant adopted in the position angle measurement. It was also recommended not to mix into a single value measurements made by different methods.

From the 1960s and in order to standardize the data for the Index Catalogue of Visual Double Stars (Jeffers *et al.* 1963, Pub. of the Lick Observatory **21**), it was recommended to provide the following information:

- α and δ for 1900 equinox and, if possible, the 2000 position.
- The ADS number
- The observed component
- The date, rounded to two decimals of a year, unless a very rapid binary is being observed, when three decimals should be given
- The position angle as observed not precessed to certain epoch (cf. §4.1.1. above).
- The angular separation.
- The estimated magnitudes or magnitude difference.
- The number of nights included in the mean.
- The aperture of the telescope and the type of instrument used for the measure.

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It is also advised to publish data in series of measures not involving large time intervals (less than 10 years) and increase the frequency of publications.

6.5. *The exploitation of data - Calculation of orbits*

The majority of observational data obtained at different runs are intended for orbital calculation. The determination of the orbital elements of a double star is vital for several fundamental parameters; in fact it is the only way to know the stellar masses. These studies have also resulted in various kinds of statistical analysis. The number of orbits calculated and the work of its authors are highlighted in every triennial report issued by Commission 26. It is also through the Commission that researchers receive relevant information and guidance in the:

6.5.1. *Work Methodology*

- Avoid calculating the same orbit, based only on small discrepancies, without a good reason.
- Distinguish between two types of orbits: those based on short arcs leading to a range of solutions with similar values, and close binary orbits.
- Calculate short period orbits, considering new observational techniques that increase not only its number but also its accuracy.
- Obtain rectilinear elements.
- Study perturbed motions. The presence of a third body with special characteristics (white dwarfs, neutron stars, planets, etc.) can be discovered from the orbital residuals. But the possible instability of secondary orbits should be taken into account.
- Calculate spectroscopic orbits.
- Speckle interferometry orbits of binary stars appear in the 1980s, i.e. those based primarily on speckle measures. Since then, the accuracy of the RV measures and speckle interferometry has increased the overlap between visual and spectroscopic binaries. The combination of the two types of data will lead to the so-called combined solution orbits allowing determination to 1% accuracy in mass.
- Analysis of orbital elements and dynamic stability of multiple systems.

6.5.2. *Calculation Methods*

Design calculation methods depending on:

- Binary type: based on relative position measurements for visual double stars or radial velocity measurements for spectroscopic binaries.
- Orbit type: elliptical, circular, parabolic or hyperbolic.
- Procedure type: analytic, graphic, geometrical, numeric, etc.
- Criteria studies for determining non-periodic orbits.
- Orbit improvement methods.
- New calculations, with computers, to reissue the rectangular elliptical coordinate tables (X,Y) according different eccentricities to facilitate orbit calculation, in order to replace an earlier publication (*Resolution 45 in the 10th GA Moscow, 1958*).
- Graphic methods to obtain ephemerides of apparent positions.
- From the 1960s, and thanks to the advancement of computer technology, there is a proliferation of orbit computation methods, both classic and modern. From the beginning, the Commission showed concern that these methods would lead to immature orbits that would serve only to increase the already superabundant number of data. Therefore, it cautions the calculators to rely on the experience and judgment of the observers.

6.5.3. *Standards in Publication*

During the scientific meeting that took place in the *5th GA (Paris 1935)*, the authors of the orbits were asked to publish the following information:

- Orbital elements: P, n, T_0, e, a$''$, i, Ω, ω.
- Thiele-Innes constants: A, B, F, G.
- C, H, pL, pN to calculate the third coordinate and the relative radial velocity.
- A circular orbit is to be indicated by: $e = 0$, $\omega = 0$ and T_0 (time when the position angle is equal to Ω).
- An orbit perpendicular to the line of sight, is to be indicated by:
  - Direct motion, $i = 0$, $\omega = 0$ and T_0 is when the position angle is equal to ω.
  - Retrograde motion, $i = 180°$, T_0 is when the position angle is equal to $360° - \omega$.

Subsequently, more data were required, such as:

- Epochs of the nodes and their radial velocities (*Resolution 2, 8th GA, Rome 1952*).
- Add to the orbits the list of measurements, its residuals and adequate ephemerides.
- Indicate the method used to calculate the orbit and the parallax.
- The epoch of orientation of the node and the epoch of osculation of the orbit; if the latter was not available, provide, at least, the weighted mean epoch if appropriate.

6.6. *Obtaining Fundamental Parameters*

The great strength of double stars lies in being the only key that opens the possibility of stellar masses. In addition, other fundamental parameters of the binaries can be indirectly discovered if spectroscopic data or photometric studies are used. These include:

- Stellar masses and mass ratio.
- Mass-luminosity relation.
- Mass density of unseen companions.
- Orbital parallax and distance to stars.
- Magnitudes and colors of individual system components.
- Spectral classifications.
- Multiple system dynamic stability.
- Formation and stellar evolution, the age of the stars.
- Astrophysical properties, effective temperatures, surface gravity and others.

6.7. *Statistical Studies*

Another concern of astronomers dedicated to the study of double stars has been the development of statistics based on the quality of the census. Results are based on observations and orbital calculations or other fundamental parameters. For example:

- Studies on the frequency of binary according to various features: wide pairs, runaway stars, trapezium systems, main sequence (MS), metal-rich and metal-poor binaries, depending on age, multiple systems, open clusters.
- Research on double star's frequency on databases of single, bright, nearby, solar neighborhood stars and others.
- Observational error analysis for different type of measures, or perturbations distribution of astrometric positions.
- Statistical tests of the orbital elements as a whole and distribution studies of individual parameters, for example:
  - Eccentricities; in wide binaries, regarding proper motions, to determine the selec-

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tion effects or to establish mass-eccentricity correlations in spectroscopic and visual orbits.

◦ Semimajor axes and separation distribution for binaries with different magnitudes or ages.

◦ Orbital periods; to establish their correlation with the semimajor axis or mass ratio.

◦ Argument of periastron distribution in orbits of spectroscopic binaries vs. the Barr effect.

• Spatial-density and mass-density studies.

• Selection effects analysis.

• Binary and different spectral types correlations.

• Mass ratio distribution.

• Statistical methods development, e.g. mass and parallax calculation of unknown orbit binaries, or of binaries with large proper motion with white dwarfs.

• The optical or physical nature of the systems.

• Statistics of the specific catalogs of binaries or data provided by large surveys (e.g., Tycho, Hipparcos, SDSS).

6.8. *Other investigations*

Aside from the above, other studies, both theoretical and other, have been carried out.

6.8.1. *Theoretical Studies*

• Concerning pairs with degenerate components.

• Formation and evolution of binaries. Formation of binaries in stellar clusters. Early orbital evolution of young binary systems with circumbinary rings. Accretion from circumbinary disk or ring onto the proto-primary and proto-secondary. Stellar dynamical evolution of the primordial binary population in young bound clusters. Evolution of double stars considering the mass loss.

• Tidal properties and its role in the dynamical and nuclear evolution of close binary systems.

• Analytical calculations and Monte Carlo simulations to study the stellar mass function.

• Binary frequency in different environments. Solar-type binaries superabundance in T associations and normal binary population in young clusters.

• 3-dimensional calculations on the evolution of embryonic protobinaries from core collapse of a molecular cloud.

• Importance of resolving the Jeans mass or Jeans length in fragmentation calculations.

• Inclusion of magnetic fields in calculations of magneto-hydrodynamical fragmentation.

• Precession of circumstellar disks and wiggly jets in binary systems and other models without precession that can generate S or C-shaped jets in binary systems.

• N-body simulations with binaries.

• Triple systems: Orbital evolution and dynamics. Comparison with results of numerical simulations for triple and multiple systems observed. Hierarchical triple systems. Stability. Distribution of unstable triple systems configurations.

• In connection to the question of the transfer of life between different solar system's planets around binary stars as targets for microbe-carrying asteroids were considered.

• Questions of the "Arrow of Time," one of the fundamental open questions in physics, and has shown that as soon as a third star is added to a binary system, the arrow of time (which is unspecified for the binary, the system being fully time-reversible) becomes specified through Kolmogorov-Sinai entropy.

- Binary stars as sources of monochromatic gravitational waves.

6.8.2. *Various Studies*

These studies can be general, or focused on a particular star, as it presents a certain astrophysical interest or because it possesses special characteristics.

- Origin, evolution and stability of systems.
  - ◦ Different origins depending on whether it is a wide or a closed pair.
  - ◦ Dynamical and geometrical characteristics in order to understand formation and possible evolution linked to the galactic environment.
  - ◦ Dynamically and/or physically young systems, including multiple stars in the solar vicinity that is close to the stability limit.
  - ◦ Orientation of orbital planes.
  - ◦ Problems on exchange of matter and period changes in close binaries.
  - ◦ Development of numerical methods for determining the structures of stars distorted by strong gravitational fields or rapid rotations.
- Multiple systems
  - ◦ With relative distances of the same order.
  - ◦ Formed by hot stars, probably unstable.
  - ◦ Among solar-type stars.
  - ◦ Study of the existence of components in hierarchical star clusters (H-clusters).
  - ◦ Relationship between small open clusters and widely separated multiple systems.
  - ◦ Testing high velocity in metal-poor wide binaries to identify several associated moving clusters in the galactic halo.
  - ◦ Stellar Rotation versus Duplicity in Open Cluster Early-Type Stars.
- The role of DS in cosmology and astrophysics
  - ◦ Cosmological conclusions relating to the age of several binaries.
  - ◦ Interpretation of X-ray emissions.
  - ◦ Studies on stellar pulsation.
  - ◦ Wide binaries for galactic studies.
  - ◦ The age of the Local Interstellar Bubble.
- Substellar Components
  - ◦ Existence of substellar companions that lie in a boundary territory between the astrometric search of DS and planetary bodies so called "jupiters."
  - ◦ Stability of planetary orbits in binary systems.
  - ◦ Discovery of young binary disks and protobinaries.
  - ◦ Detection of brown dwarfs and exoplanets. Why are stars and planets apparently common whereas brown dwarfs are uncommon?
  - ◦ Assessment of the possible observation of asteroids by DS specialists, which would allow the detection of asteroid duplicity by means of lunar occultations.
- Analysis of several types: dynamic, spectral, measurements, etc.
- Double stars with variable components.
- Spectroscopic binaries.
- Detection of possible massive unseen companions in DS, from different types of records such as lists of catalogs or photographic plates.
- Perturbation studies. Anomalies in the relative movements of binaries due to the presence of perturbed bodies. Unseen low-mass companions.

6.9. *Sponsoring of Activities*

The main activities supported and sponsored by Commission 26 usually have to do with the organization of meetings. Often they are framed within the various categories recognized by the IAU, for example: Symposia, Colloquia (which disappeared in 2005), Joint Discussions or Special Sessions (fused in the so called "Focus Meeting" since 2013, and when a new category called "Division Meetings" was introduced). They can be sponsored individually, together, or with the endorsement of other committees or working groups. Numerous conferences outside the IAU have also been held with the participation of other agencies.

IAU Symposia:

- No. 17 "On Visual Double Stars," 11-12 August 1961, Berkeley (USA)
- No. 111 "Calibration of Fundamental Stellar Quantities," 24-29 May 1984, Como (Italy)
- No. 200 "The Formation of Binary Stars," 10-14 April 2000, Potsdam (Germany)
- No. 240 "Binary Stars as Critical Tools and Tests in Contemporary Astrophysics," 22-25 August 2006, Prague (Czech Republic)
- No. 248 "A Giant Step: From Milli- to Micro- Arcsecond Astrometry," 15-19 October 2007, Shanghai (China)

IAU Colloquia:

- No. XII "On the Evolution of Double Stars," 29 August - 2 September 1966, Uccle (Belgium)
- No. 5 "La cohésion entre les procédés d'observations des étoiles doubles," 8-10 September 1969, Nice (France)
- No. 18 "Orbital and physical parameters of double stars," 12-15 April 1972, Swarthmore (USA)
- No. 33 "Observational Parameters and Dynamical Evolution of Multiple Stars," 13-16 October 1975, Oaxtepec (Mexico)
- No. 62 "Current techniques in double and multiple star research," 19-21 May 1981, Flagstaff (USA)
- No. 80 "Double Stars, Physical Properties and Generic Relations," 3-7 June 1983, Lembang (Java)
- No. 97 "Wide Components in Double and Multiple Stars," 8-13 June 1987, Brussels (Belgium)
- No. 135 "Complementary Approaches to Double and Multiple Star Research," 5-10 April 1992 , Pine Mountain (USA)
- No. 170 "Precise Stellar Radial Velocities," 21-26 June 1998, Victoria (Canada)
- No. 191 "The Environment and Evolution of Binary and Multiple Stars," 3-7 February 2003, Merida (Mexico)

IAU Joint Discussion:

- "Formation and Evolution of stars in Binary Systems," during the 20^{th} GA (1988; Baltimore USA)
- JD 5 on "Mixing and Diffusion in Stars," during the 24^{th} GA (2000; Manchester England)
- JD 13 on "Hipparcos and the Luminosity Calibration of the Nearer Stars," during the 24^{th} GA (2000; Manchester England)

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IAU Special Sessions

- "A New Classification Scheme for Double Stars," during the 25th GA (2003; Sydney Australia)

IAU Joint Commission Meetings

- "Stellar photometry with modern Array Detectors," during the 20th GA (1988; Baltimore USA)
- "Formation of Binaries" during the 20th GA (1988; Baltimore USA)
- "Nomenclature of companions to stars," during the 24th GA (2000; Manchester England)
- Splinter Session (meeting of Commissions 26, 42 & G1) during the 29th GA (2015; Honolulu USA — see §4 above)

Other Meetings

- "European Double Star Colloquium," October 1974, Coimbra (Portugal)
- "Astrometric Binaries: An International Conference to Commemorate the Birth of F.W. Bessel," 13-15 June 1984, Bamberg (Germany)
- "The Origins, Evolution and Destinies of Binary Stars in Clusters," June 1995, Calgary (Canada)
- "Visual Double Stars: Formation, Dynamics, and Evolutionary Tracks," 29 July -1 August 1996, Santiago de Compostela (Spain)
- "Spectroscopically and spatially resolving the components of close binary stars," 20-24 October 2003, Dubrovnik (Croatia)
- "Multiple stars across the H-R diagram," 12-15 July 2005, Garching (Germany)
- "Multiplicity in Star Formation," 16-18 May 2007, Toronto (Canada)
- "IV International Meeting on Dynamical Astronomy in Latin America," 12-16 February 2008, Mexico City (Mexico)
- "Double and Multiple Stars: Dynamics, Physics, and Instrumentation," 10-11 December 2009, Santiago de Compostela (Spain)
- "Binaries Inside and Outside the Local Interstellar Bubble," 10-11 February, 2011, Santiago de Compostela (Spain)
- "Binary systems, their evolution and environments," 1-5 September 2014, Ulaan Baatar (Mongolia)

6.10. *Collaboration with Other Groups or Areas*

In the 1950s, the Commission was already aware of the many problems to which answers are sought in the field of double stars. They welcomed the views of specialists from other areas, and the IAU GA was the ideal place for networking. From the 1960s, due to amount of material waiting to be observed, the convenience of a closer collaboration between double star observers, spectroscopists and astrophysicists was brought up. Clearly, sporadic collaborations are less valuable than a stable project. For this reason, Commission 26 and Commission 30 (Radial Velocities) planned joint observing programs of selected pairs. This involves classic astrometry and binary star spectroscopy, thanks to increased precision provided by modern technology. Of primary interest is the interpretation of the individual observations of radial velocities, in order to determine the ascending node of known orbits. Communicating with the astrophysical community is necessary especially in the field of binaries containing high luminosity components, subdwarf components of uncertain mass, with variable components, etc.

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The possibility to create a task force formed by members of the C26 and C42 was studied during the meeting of Commission 26 in the 13^{th} GA held in Prague (1967), but it was determined to be more convenient to combine C26 and C30. Lately, the participation between Commission 26 and Commission 54 (optical and infrared interferometry) had discussions for projects involving interferometric binaries.

It should also be noted that there is traditional collaboration between different observatories, individual astronomers, and amateur associations in multiple tasks such as: micrometer measurements, identifying relatively close pairs on celestial charts and photographic plates, observation of long-neglected stars in the Southern Hemisphere, orbit calculation, etc.

The idea of connecting, in a more official way, amateur DS experts with C26, by appointing them as consultants, emerged at the Commission 26 meeting that took place in the 24^{th} GA held in Manchester (2000). In the 2010-decade, amateur astronomers have been responsible for about $\frac{1}{3}$ of the measures of pointed observations included in the WDS database, many of which are of very high quality.

For ninety-six years the members of Commission 26 have been making measures of double and multiple stars of varying characteristics with the knowledge that some of the systems would not be ready for analysis in their lifetime. The membership has been living the words of one of our most illustrious past presidents, Ejnar Hertzsprung:

The debt to our ancestors for the observations they made to our benefit, we can pay only by doing the same to the advantage of our successors.