

DIVISION IV STARS

ÉTOILES

Division IV organizes astronomers studying the characterization, interior and atmospheric structure of stars of all masses, ages and chemical compositions.

PRESIDENT	Dainis Dravins
VICE-PRESIDENT	Monique Spite
PAST PRESIDENT	Beatriz Barbuy
BOARD	Christopher Corbally, Wojciech Dziembowski, William I. Hartkopf, Christopher Sneden

DIVISION IV COMMISSIONS

Commission 26	Binary and Multiple Stars
Commission 29	Stellar Spectra
Commission 35	Stellar Constitution
Commission 36	Theory of Stellar Atmospheres
Commission 45	Stellar Classification

DIVISION IV WORKING GROUPS

Division IV WG	Abundances in Red Giants
Division IV WG	Massive Stars

INTER-DIVISION WORKING GROUPS

Division IV-V WG	Active B-type Stars
Division IV-V WG	Ap and Related Stars

PROCEEDINGS SCIENCE AND BUSINESS MEETING on 21 August 2006

1. Division IV

The meeting of Division IV (Stars) during the IAU XXVI General Assembly in Prague was organized as mainly a science session, preceded by a short business part. In addition, its Organizing Committee had an informal meeting some day earlier. A comprehensive report on the activities of all its Commissions and Working Groups during the preceding triennium is in *Reports on Astronomy, Transactions IAU Volume XXVIA* (2007, ed. O. Engvold). In an evaluation of the activities of those bodies, it was concluded that they all were active and needed, and should continue in basically the same format also during the next triennium. One item for possible consideration, however, is the question of whether – in the longer run – perhaps some kind of merger of Commissions 29 and 36 should be considered.

2. Election of new officials

In the months preceding the IAU General Assembly, elections for a new Division president and vice-president were organized. Following discussions within the Organizing Committee, a format was chosen to assure a broader participation than was common in the past (elections



Figure 1. The Division IV Organizing Committee of 2003-2006 assembled during the IAU XXVI General Assembly in Prague. Left to right: Christopher Corbally (Vatican & Tucson; president Comm. 45; Div. IV vice-president-elect); Monique Spite (Paris-Meudon; president Comm. 36; Div. IV president-elect); Wojciech Dziembowski (Warsaw; president Comm. 35); Christopher Sneden (Austin; president Comm. 29); Beatriz Barbuy (São Paulo; former Div. IV president), William Hartkopf (Washington, DC; president Comm. 26); Dainis Dravins (Lund; Div. IV president).

held during the General Assembly, not always with very many participants), while still keeping the procedure manageable and having some assurance that the electorate be familiar with the duties expected for those serving on IAU bodies.

The electorate was defined as all members of all Organizing Committees of all Commissions within the Division, supplemented with the chairpersons of the Division-level Working Groups. Each person was to vote only once, even if holding multiple appointments. This electorate consisted of 58 persons, representing a broad range in geographic locations and thematic specialties. The votes were sent as e-mails to the Division, with 'backup' copies to the IAU Assistant General Secretary.

It was seen natural to elect the Division president from among the current Commission presidents, and each was contacted with an invitation to be a candidate. In those cases where the current presidents declined, the [immediate] past presidents were invited to be candidates. This procedure resulted in four excellent candidates (each of which received numerous votes), among whom Monique Spite was elected as the new Division president for 2006-2009, and Christopher Corbally as the new vice-president.

3. Stellar astrophysics in the 2010s

It was decided to devote most of the Division IV meeting to 'visionary science', with topics not covered at other General Assembly meetings. The title *Stellar Astrophysics in the 2010's: Extrapolating scientific challenges some decade into the future* was chosen, with the intention not to present recent results, but rather try to extrapolate (or even speculate) some decade into the future of what the scientific challenges then might be. The desire not to overlap with

topics covered elsewhere meant that, e.g., problems such as the hydrodynamic modeling of entire stars were not included, since related problems were to be treated during Symposium 239 on *Convection in Astrophysics*.

During the well-attended meeting (organized and chaired by Dainis Dravins, Lund Observatory), the following talks were given:

Jason Aufdenberg (Embry-Riddle Aeronautical University, Florida)

Interferometric stellar imaging: thoughts on probing stellar photospheres at high-resolution in the 2010's.

As steps toward the full imaging of stellar surfaces, interferometric diameters and limb darkening measures may be obtained for stars across much of the HR diagram. Solar limb darkening was measured in the 1870's, and interpreted by Karl Schwarzschild a century ago: the center-to-limb profile for the Sun was then derived with a radiative (i.e., not adiabatic) temperature structure. Limb darkening is thus a key to understanding stellar atmospheric structure, and there is a need for multi-wavelength observations extending toward the blue and violet. Models are most sensitive at short wavelengths in segregating, e.g., among models with, or without convective overshoot. The disks of rapidly rotating stars become oblate, and some have already been mapped through interferometry: Altair (A7 V) has an equator-to-polar axis ratio = 1.14; Regulus (B7 V) has 1.32, and Archenar (B3 Vpe) has 1.56! Full imaging requires a good sampling of the (u,v) plane, becoming feasible with aperture masking on extremely large telescopes, which will offer hundreds of baselines. Supergiants such as Betelgeuse and Antares will be imaged already quite soon by interferometric instruments on the Large Binocular Telescope. Prospects include the imaging of odd-shaped and never-before-seen stars, perhaps differentially rotating rapid rotators shaped like butterflies? For further information on optical stellar interferometry, see links from <http://olbin.jpl.nasa.gov/intro/> .

Andreas Quirrenbach (Landessternwarte Königstuhl, Heidelberg)

Interferometric spectroscopy across spatially resolved stellar disks

Ordinary spectroscopy of stars observed as point sources blurs all surface features together, making those awkward or impossible to disentangle. However, combining the spatial resolution of stellar disks with high-resolution spectroscopy promises to be particularly powerful. Already now, giant stars are seen to be noticeably larger in molecular bands such as TiO, than in the continuum. Interferometry may also be used to assure uniqueness in other stellar surface image reconstructions, in particular to break the north-south degeneracy often seen in reconstructions from Doppler tomography. In Mira-type stars, shocks may be traced, and surface structures identified. The orientation of stellar rotation axes on the sky can be obtained from interferometer observations in different positions. By combining such measurements with exoplanet orbital inclinations, new information on their possible alignments can be obtained. Further, the possible axis alignments of stars in binaries or clusters may be studied. A spectral resolving power $R \approx 60,000$ is required, feasible to realize in a proposed project utilizing the UVES spectrometer at ESO's Very Large Telescope (VLT). A fiber link would bring two phase-stable beams from the VLT interferometer to UVES, where the light would be spectrally dispersed just as from any other source. For a barely resolved star of magnitude 7, signal-to-noise ratios of 30 should be reachable for each spectral element, using interferometer telescope apertures of 75 cm. Observational issues include the handling of phase delay changes during integration, caused by the terrestrial atmosphere. Further information on various VLT interferometer projects can be found at <http://www.eso.org/projects/vlti/> .

Rafael Bachiller (Observatorio Astronómico Nacional, Madrid)

Stellar evolution: prospects with ALMA

Currently under construction at 5,000 m altitude on the Andean altiplano in northern Chile, the Atacama Large Millimeter Array (ALMA) is a radio interferometer to comprise up to 64 twelve-meter diameter antennas with about 8,000 m² of aperture (including the ALMA Compact Array system). With its good coverage of the mm and the sub-mm ranges, ALMA will greatly expand the field of stellar astronomy and, in particular, will revolutionize our knowledge of the two ends of stellar evolution. On one hand, ALMA will be the first telescope capable of resolving the key processes taking place during the collapse of star-forming clouds, the structure of protostars, the origin of proto-stellar outflows, and the physics and chemistry of proto-planetary disk systems. On the other hand, ALMA will allow the direct observation of

dust formation processes in AGB stars and will provide crucial details on the structure and composition of the dust and molecular material in the circumstellar envelopes of AGB stars, post-AGB objects, and planetary nebulae, leading to an unprecedented and detailed view of the late stellar evolution. Further information on the highly international ALMA project can be found at <http://www.eso.org/projects/alma/>, <http://www.cv.nrao.edu/naasc/>, <http://www.nro.nao.ac.jp/alma/>, and further links from these.

Karl Menten (Max-Planck-Institut für Radioastronomie, Bonn)

Submillimeter analyses of stellar photospheres

ALMA will have about 100 times better continuum sensitivity than existing radio arrays, and will open up radio studies of also ‘normal’ stars. Detection of a nearby star such as α Cen A (which, at some 20 milliarcsecond [mas] diameter remains spatially unresolved) with a flux of some 27 mJy at 345 GHz will be possible already within seconds of integration. Adaptive calibration using stellar photospheres of nearby stars will permit very deep integrations, offering the possibility of radio detection of extrasolar planets. A possible ‘Jupiter’ around α Cen would be 4 arcsec away, have a flux of 6 μ Jy at 345 GHz, and be potentially detectable. Giant and supergiant stars are expected to have quite different sizes (and shapes?) for their ‘optical photosphere’, ‘radio photosphere’, ‘molecular photosphere’, and the outer shells of SiO and H₂O masers. Maser emission sources could further be used as ‘guide stars’ for calibrating a possibly very weak photospheric continuum emission. The inner envelopes of at least supergiant stars will be imaged with ALMA, revealing the structure of the radio photosphere; of atmospheric chemistry; of dust formation and depletion, and showing the beginning stellar-wind outflow. Other future radio facilities of significance for stellar studies include the Expanded Very Large Array (maximum spatial resolution to be improved to some 5 mas; <http://www.aoc.nrao.edu/evla/>), and of course the future Square Kilometer Array (<http://www.skatelescope.org/>).

Lennart Lindgren (Lund Observatory)

Browsing for rare stellar types in the Gaia catalog

One lesson learned from the previous space astrometry mission *Hipparcos* is that astrometric data, however comprehensive, must be complemented by photometric and spectroscopic information to become widely usable. The *Gaia* space astrometry mission is to measure more than a billion stars, and is to collect also such complementary data. Photometry will be made in the wide G-band (330–1050 nm) at full spatial resolution, and in blue and red portions using a dispersing prism. Expected precision per observation for a 15 mag star is 0.002 mag in G, and 0.02 mag per spectral resolution element in the prismatic modes. Radial-velocity measurements will be made for stars brighter than 17 mag, using the infrared Ca II triplet for accuracies of 1–10 km s⁻¹. During the five-year mission, each star will typically be observed during \approx 100 epochs.

The *Gaia* database will offer globally calibrated data for many millions of objects. For example, the number of stars with relative uncertainty in distance better than 1% is expected to exceed 10 million. Probably, stars in very rare evolutionary phases (e.g., post-AGB) will be found, as will such of especially high or low luminosity; of high or low metal content. Perhaps one will identify radial orbits in the Galaxy for the first stars? Or black holes in non-interacting binaries (not visible in X-rays) that need astrometry for identification? Nearby stars with (accidentally) small proper motions might emerge; as could very wide binaries or loose stellar groups. However, efficient data-mining algorithms will be required since data will still be inhomogeneous in terms of accuracy (dependent on the apparent magnitude), and since spurious outliers in the data can not be avoided (e.g., such caused by detector noise): even a very low frequency of such will produce many among the more than a billion objects studied. With a currently planned launch date in 2011, nominal observations would start in 2012 and, following some early data releases, the final catalog would become available in 2020. Further information on the *Gaia* mission can be found at <http://www.esa.int/science/gaia>.

Ken Carpenter (NASA Goddard Space Flight Center) & SI Vision Mission Study Team

Stellar Imager (SI) space mission: stellar magnetic activity

The *Stellar Imager* (SI) is a planned ultraviolet and optical, space-based interferometer, designed to enable spectral imaging of stellar surfaces and stellar interiors (via asteroseismology) and of the Universe in general, with a 0.1 milliarcsecond spatial resolution. *SI* was identified as a ‘Flagship and Landmark Discovery Mission’ in the 2005 Sun Solar System Connection (SSSC)

Roadmap and as a candidate for a 'Pathways to Life Observatory' in the Exploration of the Universe Division (EUD) Roadmap (May, 2005). The ultra-sharp images from the *Stellar Imager* will revolutionize our view of many dynamic astrophysical processes: The 0.1 mas resolution of this deep-space telescope will transform point sources into extended ones, and snapshots into evolving views. *SI's* science focuses on the role of magnetism in the Universe, particularly on magnetic activity on the surfaces of stars like the Sun. *SI's* prime goal is to enable long-term forecasting of solar activity and the space weather that it drives in support of the 'Living With a Star' program in the 'Exploration Era'. *SI* will also revolutionize our understanding of the formation of planetary systems, of the habitability and climatology of distant planets, and of many magneto-hydrodynamically controlled processes in the Universe. A mission architecture has been defined that can meet the science goals, involving a group of 1-m class telescopes flying in formation, and forming an optical Fizeau interferometer with a light-combining hub at its center. Additional information on the *SI* mission concept and related technology development can be found at <http://hires.gsfc.nasa.gov/si/> .

Webster Cash (presented by Eric Schindhelm) (CASA, University of Colorado, Boulder)

MAXIM - coronal structure with X-ray interferometry

MAXIM (Micro-Arcsecond X-ray Imaging Mission) is a proposed space mission with an imaging X-ray interferometer producing images with 0.1 microarcsecond resolution. Under such resolutions, many stellar coronae become highly extended sources, with a potential for detailed imaging. The short wavelengths of X-rays imply that the required baselines for a given spatial resolution can be 100 to 1,000 times smaller than those in the optical and infrared bands. Diffraction-limited X-ray optics with a size of meters can yield an angular resolution of milli-arcseconds, which would be sufficient to resolve coronal structures on nearby stars, while the X-ray interferometry envisioned for *MAXIM* may improve resolution by further orders of magnitude. Formation-flying spacecraft are envisioned, positioned to 25 μm precision. One main scientific aim of the mission is to image black holes and their X-ray-emitting immediate vicinities (only few black holes have their Einstein radii greater than some microarcsec). The full mission could be preceded by a 'MAXIM Pathfinder' spacecraft, providing 100 microarcsecond resolution. Alternative mission designs include normal-incidence optics, while technical issues include questions such as how to point a microarcsecond telescope. Additional information on the *MAXIM* mission concept can be found at <http://maxim.gsfc.nasa.gov/> .

4. Closing remarks

Following the Division IV meeting, it was generally agreed that stellar astrophysics has an exciting future for the 2010s and beyond. The advent of extremely large optical telescopes and interferometers, will make many stars accessible as extended surface objects rather than the mere point sources of the past. Radio interferometers are becoming sufficiently large and sensitive to enable the study of also 'ordinary' stars, not only the most active ones detectable in the past. Large-scale surveys of stars in both our own, and neighboring Galaxies will enable the identification of also rare types of stars, or stars in short-lived evolutionary stages, while space missions further ahead promise to enable a quite detailed imaging of active-region structures across stellar surfaces, and their evolution over both short timescales, and over stellar activity cycles. We indeed look forward to experiencing such a stellar future!

Dainis Dravins
president of the Division