Report on the ESO Workshop

The Origin and Fate of the Sun: Evolution of Solar-mass Stars Observed with High Angular Resolution

held at ESO Garching, Germany, 2–5 March 2010

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The goal of the workshop was to review recent results on solar-mass stars obtained with infrared and millimetre interferometers, and to discuss their importance for our understanding of stellar evolution from star formation to the late stages. The workshop was preceded by a one-day ALMA+VLTI interferometry primer. A brief summary of the workshop is presented.

Figure 1. Participants in the interferometry primer.

The workshop was organised with a focus on solar-mass stars, and the intention of following their evolution through the Hertzsprung–Russell (HR) diagram in the light of the new interferometric observations. The goals included presenting the unique results made available by interferometry, discussing the complementarity between infrared and millimetre interferometry, merging them with observations obtained with other techniques, such as spectroscopy, and discussing their impact on the details of the evolution of Sun-like stars. Another goal was a presentation of the prospects with second generation VLTI instruments and with ALMA.

Several years of observations using the VLT Interferometer (VLTI) have allowed us to gain unprecedented new insights into different stages of stellar evolution from star formation to the late stages, using the combination of high spatial and spectral resolution. Examples are discs around young stars, debris discs, stellar atmospheres and the circumstellar environment of evolved stars. Now, the upcoming dual-feed facility PRIMA on the VLTI is about to enable astrometric measurements, with one goal being the detection and characterisation of planets around stars. In the immediate future, ALMA will provide complementary observations of stars with similar angular resolution compared to the VLTI, but at sub-mm wavelengths. ALMA will observe the chemical cycle of the interstellar medium from the formation of molecules and dust in late-type stars and in molecular clouds to the formation of stars and planetary systems, and possibly probe the chemistry of pre-biotic molecules in nearby forming planetary systems and in our own Solar System.

With the first generation of VLTI instrumentation reaching maturity, the work on second generation instruments well advanced and the opening of the ALMA Early Science due on a timescale of one year, the workshop was very timely with the presentation of many new results and an overview of the future possibilities.

Interferometry primer

The science sessions of the workshop were preceded by a one-day ALMA+VLTI interferometry primer. It was organised with the aim of enabling attendees without experience in interferometry to advance from the basics and to be able to assess the interferometric results presented during the workshop and to develop project ideas for discussion. The morning of the primer was dedicated to the principles of interferometry in general and the techniques to implement them in the infrared and radio wavelength regimes. The afternoon session focused on the practical use of ALMA and the VLTI, including the opportunities to use these facilities, the preparation of observations and the data reduction. A feedback chart showed that the vast majority of the participants in the primer (see Figure 1) were indeed highly interested in both the VLTI and ALMA, and that the primer was perceived as being useful for their work.

From young stellar objects to main sequence stars

The science sessions started with a discussion of molecular clouds and the first stages of stellar evolution, from protostars to the main sequence, and the formation, detection and characterisation of planets. Recent interferometric measurements at near-infrared, mid-infrared, centimetre and millimetre wavelengths were presented. The latest results presented in these areas from the VLTI are currently transforming our understanding of the disc–star interaction and the inner regions of protoplanetary discs. The VLTI is already approaching the frontier of imaging the inner discs, an area which will flourish with the second generation instruments.

The expected impact of ALMA was emphasised with the presentation of results from the current generation of (sub)millimetre arrays. The progress expected in the areas of the structure and chemistry of clouds and the earliest phases of collapse of molecular cores is enormous, as the improved sensitivity and frequency coverage will allow detailed studies of the less abundant species. If the study of these early phases is mostly believed to be the realm of ALMA, the synergy of infrared and millimetre observations

is expected to produce a spectacular advance in our understanding of the structure of young stellar objects and protoplanetary discs (see Figure 3). The discussion focused on the continuum of disc properties from primordial discs to debris discs and planet formation and their further evolution toward giants and white dwarfs. Several unsolved questions were raised, such as, for example, how the true disc mass can be measured, how disc properties can be constrained in the areas we can’t spatially resolve, how larger bodies can be traced, how pre-main sequence tracks can be better constrained, and what happens to debris discs and planets once the star leaves the main sequence. The combination of VLTI and ALMA measurements will allow us to obtain comprehensive, high angular resolution observations of the dust and gas evolution in discs, both essential ingredients for our understanding of the planet formation process.

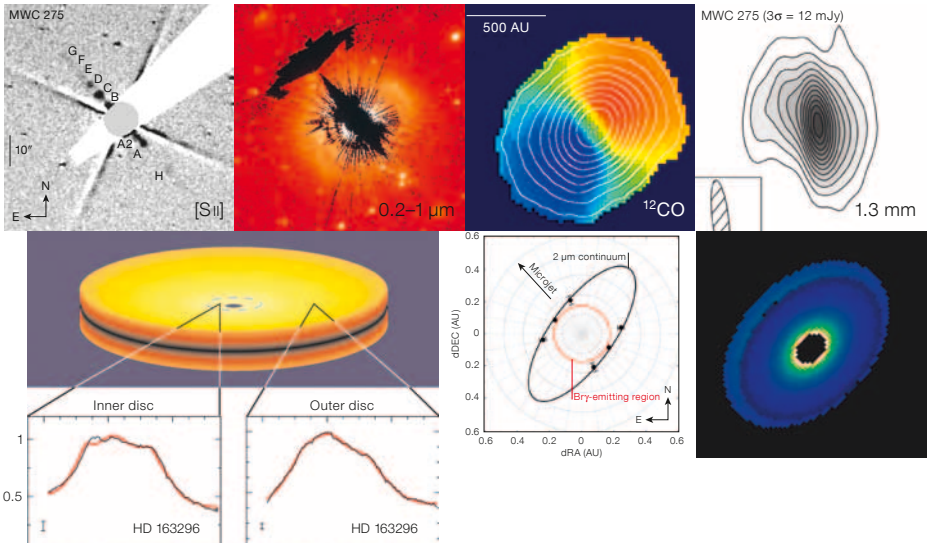
Figure 2. Participants of the workshop in the entrance hall at ESO Headquarters.

From the main sequence to late stages of evolution

The session on stellar evolution from the main sequence onward started with overviews on the current state-of-the-art of stellar evolution as well as stellar atmospheres, and, in particular for evolved stars, on the latest hydrodynamic model atmospheres. The session included presentations of the newest results in the fields of red giant branch (RGB), asymptotic giant branch (AGB), post-AGB stars and planetary nebulae (PNe). Infrared interferometry with the VLTI and other interferometers has made enormous progress, in particular in studying the details of the molecular and dusty shells around AGB stars. By comparison to the latest hydrodynamic wind models, these studies address the unsolved problem of mass-loss and the dust driving mechanisms. For post-AGB stars, the emphasis of the presented results was placed on the origin and evolution of discs — connecting the session back to the first session on young stellar objects, on binarity, magnetic fields and the shaping mechanisms in general. Presented observations, using radio and millimetre interferometers, such as the Very Large Array (VLA), the Very Large Bolometric Array (VLBA), Merlin, or the Institut de Radioastronomie Millimétrique (IRAM) Plateau de Bure Interferometer, trace the mass-loss through the maser and dust zones in a complementary way (see Figure 4). They show an amazing chemistry and allow investigations of the nucleosynthesis in AGB stars.

The synergy of the VLTI and ALMA will again be essential in the further study of the dust production in AGB stars and their yields to the interstellar medium. The ALMA angular resolution is very well-matched with the size of the structures in AGB radio photospheres and envelopes, allowing their detailed study. Of particular interest will be the study of the millimetre transitions of water and its isotopes, especially with the ALMA Band 5 receivers, a small set of which are being built in the framework of the ALMA Enhancement project funded by the European Commission as part of the FP6 actions. During the discussions on these sessions, one question was how detailed theoretical models need to be for comparison to observations and how they can best be made readily available. Another point of discussion was that many of the presented results focused on rather extreme AGB stars, and whether we might miss the characteristics of less extreme giant stars that make up the majority in stellar populations.

Figure 3. A collection of results on HD 163296 from the presentation by Stefan Kraus. HD 163296 is a young disc very well observed in the millimetre range and with the VLTI. These results nicely illustrate the complementarity of millimetre and infrared interferometry for the same source. The figure includes results by Wassell et al., 2006; Grady et al., 2000; Isella et al., 2007, 2009; van Boekel et al., 2004; Kraus et al., 2008; Benisty et al., 2010 (from left to right and top to bottom).



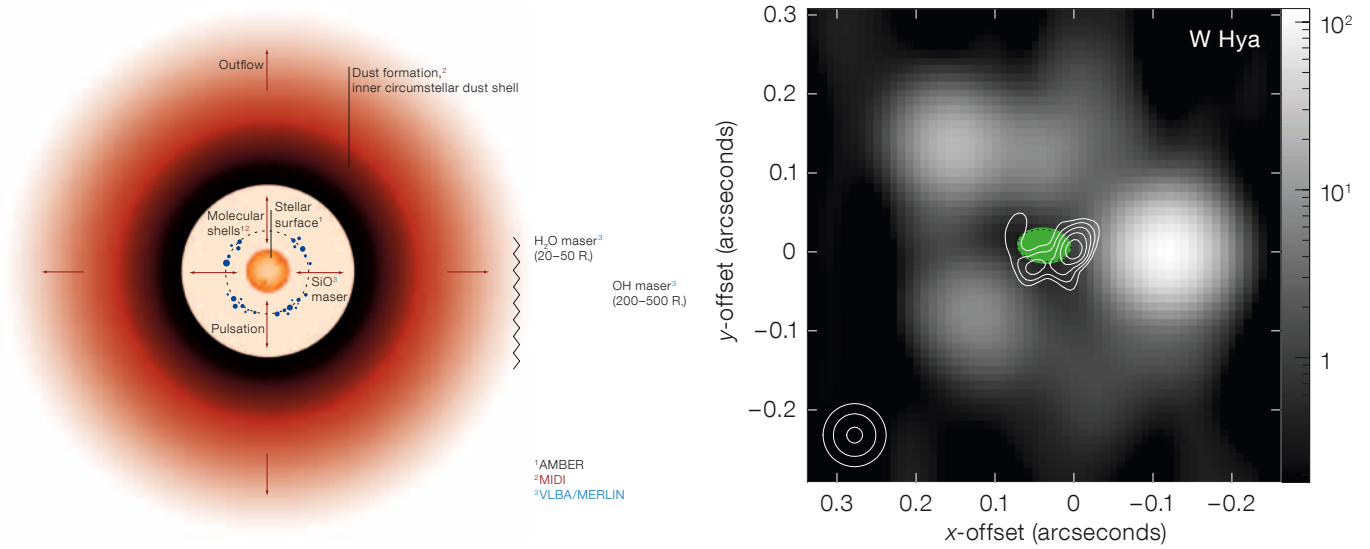


Figure 4. Left: A sketch of the atmosphere and circumstellar environment of AGB stars, as shown during the workshop in the presentation by Iva Karovicova (Credit: ESO/ePOD). The different regions can be studied by infrared, millimetre, and radio interferometers in a complementary way. Right: Recent simultaneous observation of the radio photosphere (green), the SiO maser shell (contours), and the H_2O maser shell (gray scale) of the AGB star W Hya, from Reid & Menten (1990, 2007), as shown during the workshop in the presentation by Karl Menten.

Facilities

The workshop ended with two presentations on the observational opportunities with the VLTI and the prospects with ALMA for solar-mass stars. Current VLTI instruments include the near-infrared instrument AMBER and the mid-infrared instrument MIDI. These instruments have already produced more than 100 refereed publications, most of which are in the field of stellar physics. First images based on VLTI data have already been obtained (cf. Kraus et al., 2009; Le Bouquin et al., 2009). The astrometric facility PRIMA (cf. van Belle, 2008) is being commissioned, and the second generation VLTI instruments MATISSE and GRAVITY are being designed. MATISSE is a four-beam mid-infrared in-strument with the capability of providing reconstructed images; the main science cases are investigating star and planet formation, in particular tracing protoplanets, active galactic nuclei, evolved stars and Solar System minor bodies. GRAVITY is a four-beam near-infrared (2.2 μm) instrument with a spectral resolution of 20 to 4000, with internal fringe tracking and dual-feed, with its own infrared adaptive optics, and an astrometric precision of 30 micro-arcseconds. Its main science goals include the detection of special and general relativistic effects in the cusp star orbits and other cases around the Galactic Centre, orbits of extrasolar Jupiter/Uranus mass planets, imaging jets and discs in young stellar objects, proper motions in massive star clusters and stellar motions and gas flows in galactic centres.

ALMA is designed and being built with the goal of providing, also to non-radio interferometry experts, an instrument to obtain high fidelity, high resolution and high sensitivity 3D images (cf. Haupt & Rykaczewski, 2007; Tan et al., 2009). The main science goals of ALMA cover the evolution of interstellar matter and star formation across the Universe as well as the detailed study of the chemical complexity in our own Galaxy and the Solar System. A comprehensive account of the science expected with ALMA is collected in the ALMA Design Reference Science Plan (cf. Testi, 2008). Science topics for solar-mass stars include the physical and chemical conditions of molecular clouds and the origin of the stellar initial mass function, the structure of protostars, protoplanetary disc evolution and the birth of planets, as well as the production of dust and complex molecules in the late stages of stellar evolution. ALMA is expected to announce the opportunity for Early Science observations with sixteen antennas, four frequency bands and baselines up to ~ 1 km by the end of 2010 or early 2011. During the early years, ALMA will constantly grow in its capabilities, eventually reaching Full Science Operations with the full complement of antennas, receivers and baseline lengths, expected for 2013.

Overall, the excellent presentations at the workshop provided an interesting and exhaustive overview on the current problems of stellar physics for solar-mass stars. Common problems in stellar evolution were discussed, such as the structure of discs for young stellar objects, Be stars and post-AGB stars. The role of infrared as well as millimetre interferometry to provide spatially resolved information was highlighted throughout the workshop. Often, the complementarity of the two was emphasised, stressing that the combination of different wavelengths can solve model ambiguities inherent in spectral energy distribution (SED) modelling and single-wavelength observations. Many presentations included comparisons with sophisticated theoretical modelling, such as hydrodynamic wind models for evolved stars, models of the disc structure around young stellar objects (YSOs), or a comparison of stellar parameters with evolutionary calculations. Presentations of the combination of interferometric techniques with other techniques, such as high resolution spectroscopy or adaptive optics imaging were also mentioned, such as for active stars or fundamental parameters of evolved

stars. On this aspect, more insights into the physical mechanisms can probably be expected when such attempts become more frequent. Although the workshop focused on solar-mass stars, many presentations also included related work on higher mass stars, such as the connection between solar-mass and high-mass young stars, or between AGB stars and supergiants.

All the talk and poster presentations, including the presentations of the interferometry primer, are available from the website of the workshop[1] in PDF format.

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Links

[1] http://www.eso.org/sci/meetings/stars2010

Report on the ESO/ESA Workshop

JWST and the ELTs: An Ideal Combination

held at ESO Garching, Germany, 13–16 April 2010

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ESA and ESO jointly organised a workshop to explore the synergies between the JWST and ground-based, extremely large telescopes (ELTs). The main goal of the workshop was to bring the JWST and ELT (GMT, TMT, E-ELT) communities together, to identify the common science cases, and to outline instrumentation/upgrade priorities for the ELTs that would maximise the scientific return in key areas of scientific research requiring both facilities, namely: The End of the Dark Ages — First Light and Re-ionisation; The Assembly of Galaxies; The Birth of Stars and Protoplanetary Systems; and Planetary Systems and the Origins of Life. A lively meeting with intense discussions brought some interesting insights.

Motivated by the advance of the three international Extremely Large Telescope (ELT) projects: the Giant Magellan Telescope (GMT), the Thirty Meter Telescope (TMT) and the European Extremely Large Telescope (E-ELT), as well as by the rapid progress towards a launch in 2014 of the James Webb Space Telescope (JWST), the European Space Agency (ESA) and ESO decided to jointly organise a meeting in order to explore the synergies between these facilities.

Astronomers can look back on two very successful decades of science dominated by the interplay between the Hubble Space Telescope and the 8–10-metre-class ground-based telescopes. The lessons learned from this powerful combination are being taken into account by the new projects. Some similarities to the past exist: JWST will lead the ground-based ELT projects by a few years and it is a facility that has its strength in imaging and low-resolution spectroscopy combined with exquisite sensitivity. The ground-based ELTs will follow with a vastly superior photon-collecting power and a large and versatile number of scientific instruments. A few aspects will also differ. JWST will focus on longer wavelengths, with its main strength in the infrared and it will also have a limited lifetime of around 5+5 years, due to limited fuel. Also, the ELTs, assisted by adaptive optics, will provide a spatial resolution of almost an order of magnitude better than JWST. Thus, not only very high spectral, but also very high spatial, resolution might become the domain of the ground-based telescopes.

With this in mind, close to a hundred participants from Europe, North and South America as well as East Asia joined for the four day meeting held at ESO Headquarters in Garching, Germany. The sessions were not only of very high quality, thanks to very well prepared speakers, but were also very lively, with interesting and fruitful discussions. All talks can be found online on the web pages of the workshop[1].