Report on the ESO Workshop

Dynamics of Low-mass Stellar Systems: From Star Clusters to Dwarf Galaxies

held at ESO Vitacura, Santiago, Chile, 4–8 April 2011

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The dynamics of low-mass stellar systems is not only an interesting subject in its own right, but is also intimately linked to global theories of structure formation, the physics of gravity, and the shape of the stellar initial mass function. Given the wealth of new information gathered very recently in this field, the time was ripe to hold a dedicated meeting on this topic. The workshop brought together a mix of about 100 astronomers who work on both the observation and theory of the dynamics of dwarf galaxies and star clusters, and a total of around 60 oral presentations and about 25 posters were presented.

At the low-mass end of stellar systems, there used to be a well-known dichotomy. On the one hand, there are star clusters with typical sizes of a few parsecs (pc), whose internal dynamics can generally be well described by Newtonian gravity. On the other hand, there are the much more extended dwarf galaxies with sizes of several hundred pc, whose dynamics appear to be dark matter dominated and which are usually related to cosmological substructures (see Figure 1). These classical boundaries have been blurred by the recent discovery of new classes of stellar groupings, such as ultra-faint dwarf spheroidals, ultra-massive super star clusters, ultra-compact dwarf galaxies (UCDs), and dark-matter-poor tidal dwarf galaxies (TDGs).

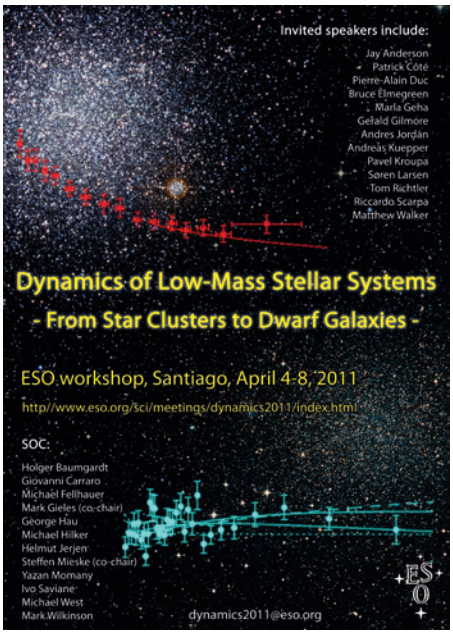

Figure 1. Conference poster, showing ESO images of Omega Centauri at the top left, and the dwarf galaxy Sculptor at the bottom right. The red and blue curves show the radial behaviour of stellar velocity dispersions in these objects (from Scarpa & Fallomo, 2010; Walker et al., 2009). The flat profile for the dwarf galaxy is typically interpreted as indicating the presence of dark matter.

The idea of our workshop, Dynamics of Low-mass Stellar Systems: From Star Clusters to Dwarf Galaxies, was to discuss the internal dynamics of these systems and their use as tracer particles in large-scale potentials. Special emphasis was placed on how the observed dynamics are linked to a more global context of structure formation theories, including a discussion of the concordance cosmological model and possible alternatives. Another focus of this meeting was the transition region between classical star clusters and dwarf galaxies, in particular UCDs.

Internal dynamics of compact stellar systems

The meeting began with a full-day session on the internal dynamics of compact stellar systems. The star cluster mass function and its evolution with time was the main topic of the morning session. Overview talks on this topic were delivered by A. Jordan, B. Elmegreen, S. Larsen and P. Goudfrooij. Clusters in nearby galaxies form with a power-law mass distribution, with indications for a truncation around a few 10^5 solar masses (Larsen). The mass distribution function of old clusters peaks (when using logarithmic mass bins) at around that mass (Jordan, Elmegreen). Despite our long-established understanding of the dynamical evolution of clusters, there is still no consensus on whether the old cluster mass function can be the result of the (dynamical) evolution of a universal power-law distribution, as observed at young ages in the present epoch.

The mass-size relation (or lack thereof) among star clusters was discussed by M. Gieles, a topic that was brought up again several times during the meeting (see also Figure 3). Star cluster sizes seem to be uncorrelated with their masses up to a few million solar masses. Above this, in the realm of UCDs, size increases with mass, joining an extrapolation of the relation for giant galaxies. It was suggested that the lack of a mass-size relation of clusters is the result of dynamical evolution of star clusters away from a primordially existing relation. Subsequently the dynamical evolution of star clusters under the influence of external tides (J. Penarrubia & A.L. Vari) and internal

Figure 2. Conference photo taken in the garden of ESO's Vitacura premises.

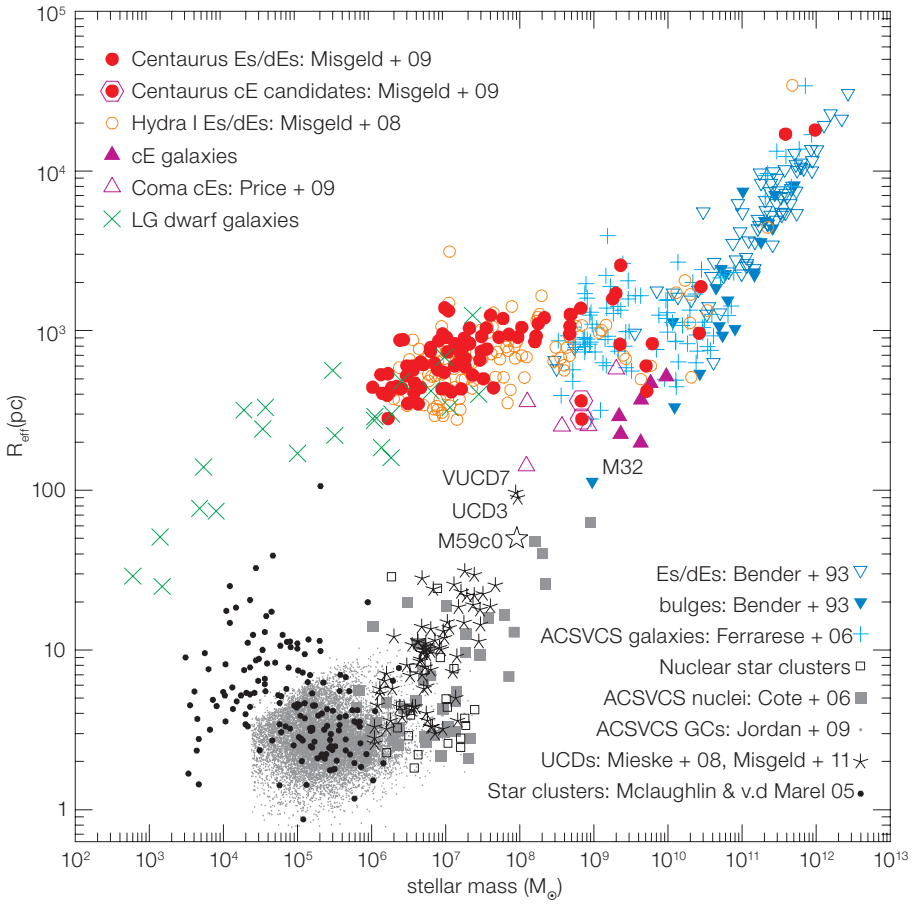

Figure 3. Effective radius plotted *vs.* stellar mass for all pressure-supported stellar systems (from Misgeld & Hilker, 2011). This plot was repeatedly shown during the workshop and the dynamics of systems with masses below ~10^8 solar masses were discussed. Dwarf galaxies are typically larger than 100 pc, while star clusters and UCDs are below that size.

effects (R. Smith & L. Smith) were discussed.

In the afternoon session, several talks on the test of Modified Newtonian Dynamics (MOND) with star cluster dynamics (R. Scarpa, R. Sollima & R. Lane) were presented. Those talks generated a very lively discussion on whether the suggested flattening of the dispersion profile in the outskirts of some clusters is caused by a breakdown of Newtonian gravity, the influence of tidal fields, or contamination. More work, especially in terms of accurate dynamical modelling, will be needed to draw firm conclusions on this matter. The afternoon continued with a review of dynamic evolutionary modelling of globular clusters by D. Heggie, who showed that a proper N-body simulation of a massive globular cluster can(not?) be performed in a human lifetime. The first day wrapped up with talks on the observed internal dynamics of nearby star clusters (A. Stolte & N. Bastian), and we learned that globular clusters (GCs) in Andromeda appear to have dynamical masses that are too low to be possibly explained by pronounced dynamical evolution (J. Strader).

Internal dynamics of dwarf galaxies

The second day of the workshop was dedicated to the dynamics of dwarf galaxies. The scene was set by review presentations on the observed internal dynamics of ultra-faint, classical and tidal dwarf galaxies by M. Geha, M. Walker and P.-A. Duc, respectively. The influence of contaminators and binaries on the derived velocity dispersions was discussed; issues that are of special importance for the faintest dwarf galaxies. It was concluded that most of the Local Group dwarfs have internal dynamics that are consistent with them being dark matter dominated, with some ongoing debate on a few ultra-faint dwarfs. It was furthermore shown that TDGs may require a moderate amount of dark matter (baryonic or non-baryonic) to explain their internal dynamics. Presentations by J. Bullock and M. Bovill drew attention to the problems of the concordance Lambda Cold Dark Matter (ΛCDM) cosmological model in explaining the observed low frequency of bright satellites.

Several presentations then focused on the dynamics of individual Local Group dwarf spheroidals (S. Pasetto, S. Zaggia & E. Lokas) including a comparison between Milky Way and M31 dwarf spheroidals (E. Tollerud). It appears that M31 dwarfs have on average lower mass-to-light (M/L) ratios at comparable luminosities. It was stressed that stochastic fluctuations may be a serious limiting factor in the predictive power of ΛCDM for individual host halos such as the Milky Way or M31. G. Mamon, M. Wilkinson and J. Wolf discussed important aspects of dynamical modelling of dwarf spheroidal galaxies from a theoretical point of view. The afternoon talks were completed by a review by P. Kroupa of the problems of ΛCDM in the Local Group, proposing a scenario where all dwarfs are formed as TDGs without any dark matter. It was shown that galaxy encounters can create counter-rotating tidal debris reminiscent of today's dwarf galaxies (M. Pawlowski). G. Hensler presented the chemo-dynamical aspect of dwarf galaxy evolution in a ΛCDM scenario.

A "hot" discussion session led by M. Wilkinson concluded the second workshop day. The apparent problems of ΛCDM in explaining the properties of Local Group galaxies for a range of masses were debated. This included the missing-satellite problem that extends to higher masses than traditionally reported, and the disc of satellites, the highly anisotropic distribution of Milky Way dwarfs. At the same time, the problems and failures of alternative approaches like MOND to provide a full framework for explaining our observed Universe were highlighted.

Black holes in low-mass stellar systems

The third day focused on black holes in low-mass stellar systems, and whether star clusters extend the well-known mass–sigma (M–σ) relation of giant galaxies to lower masses. J. Anderson showed that, from HST-based proper motion measurements, there is currently no evidence for intermediate-mass black holes in the centres of massive Galactic star clusters. This differed from the results of radial velocity studies via spectroscopy (presentations by N. Luetzgendorf, B. Jahlali & E. Noyola; see Figure 4), which suggest black holes of several tens of thousands of solar masses in a couple of Galactic star clusters. Direct comparison of proper motion and radial velocity data for Omega Centauri showed that the discrepancy can only partially be explained by uncertainties in the adopted cluster centre. H. Baumgardt reviewed the dynamical evolution of star clusters in the presence of black holes. Finally, N. Neumayer showed that several nuclear star clusters contain a comparably massive black hole. Whether or not star clusters follow the extrapolation of the M–σ relation to lower masses is still an open issue, and addressing this problem faces some fundamental limitations due to the finite number of stars that can be used as dynamical tracers in the centres of star clusters. The third workshop day was wrapped up by a dedicated poster session with 20 short presentations.

Star clusters as tracers in large scale potentials

The fourth day of the workshop shifted from the internal dynamics of low-mass stellar systems to their use as tracers in large-scale host galaxy potentials. P. Coté reviewed the link between globular cluster subpopulations and their host galaxy merger histories. This topic was discussed further in presentations by J. Brodie, R. Sanchez-Janssen and A. Huxor. T. Richtler, A. Romanowsky and V. Pota gave an overview of how the kinematics of globular cluster systems can be used to constrain the dark matter halo shape of giant galaxies. The dynamical evolution of star clusters in an external tidal field was discussed in presentations by A. Kuepper, D. Kruijssen, S. Bird and F. Renaud. I. Misgeld then gave an overview of structural and dynamical properties of “hot” stellar systems over ten orders of magnitude in mass (see Figure 3).

The dwarf galaxy – star cluster interface

The earlier presentations then set the scene for the last session of the fourth day which was dedicated to UCDs — the stellar systems at the interface between star clusters and dwarf galaxies. M. Hilker reviewed the general properties of UCDs. M. Frank presented fresh results on the spatially-resolved internal kinematics of the most massive UCD (see Figure 5). He finds that its kinematics are fully consistent with a “normal” star cluster, with no evidence for the presence of dark matter or a black hole. This was considered an important step forward in our understanding of UCDs and their origin. C. Bruens then showed *N*-body simulations, which suggested that UCDs may well be formed by the merging of individual massive star clusters, and M.

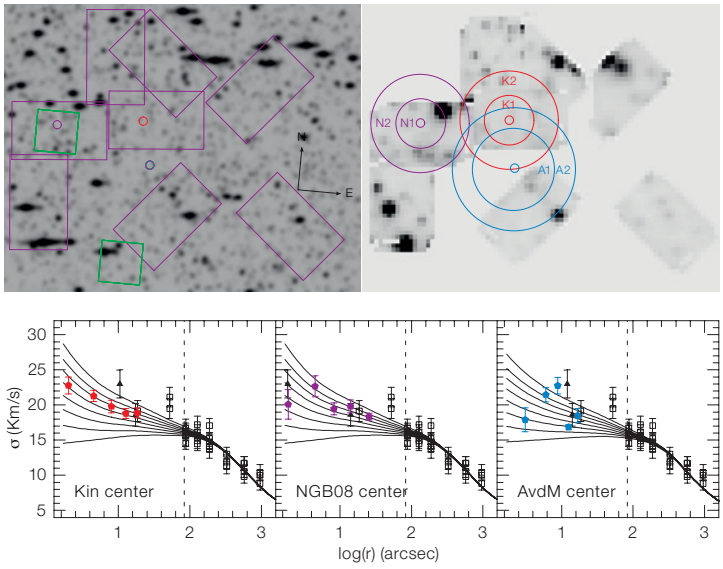

Figure 4. Kinematics of the centre of Omega Centauri measured with the FLAMES–ARGUS spectrograph at the VLT, as presented by E. Noyola at the workshop (Noyola et al., 2010).

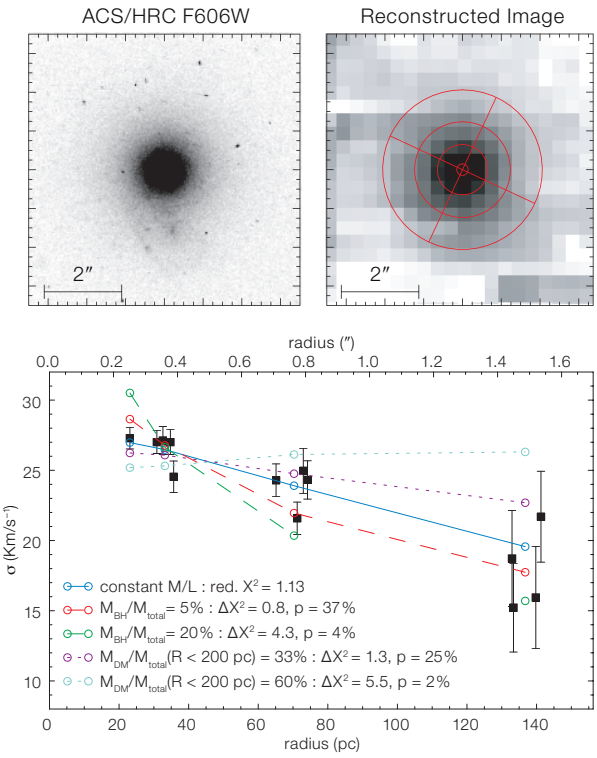

Figure 5. Spatially resolved internal kinematics of Fornax UCD3 measured with the FLAMES–ARGUS spectrograph, as presented by M. Frank at the workshop (Frank et al., 2011).

Norris discussed the ensemble properties of UCDs in a statistical sense.

The fourth day concluded with a discussion session led by S. Mieske. It was noted that the frequency of UCDs is consistent with the hypothesis that they constitute the bright tail of the globular cluster luminosity function. UCDs can be explained as massive star clusters, whose elevated M/L ratios are due to a non-canonical initial mass function. On the other hand, the formation of UCDs via tidal stripping cannot be excluded as an additional channel, given the observational evidence of tidal disruption of dwarf galaxies. Another topic of discussion was whether star clusters would be expected to trace the M–σ relation to a lower value of σ. It was concluded that this would strongly depend on the formation mechanism of putative massive black holes in them.

The last day of the workshop was again dedicated to the interface between star clusters and galaxies. D. Forbes discussed the definition of a galaxy, showing that the presence of multiple stellar populations is considered the most defining feature for a galaxy, according to an online poll amongst astronomers. K. Woodley discussed the star cluster to UCD transition based on an extensive study of the globular cluster system of the nearby elliptical galaxy Centaurus A (NGC 5128). G. da Costa showed new results on the stellar dynamics in the outskirts of Omega Centauri, arguing that possible deviations from a Keplerian velocity dispersion profile are likely due to tidal effects and/or interlopers. P. Assmann and J. Hurley focused in their talks on dwarf galaxy formation via star cluster mergers. The last session was rounded off by presentations on nuclear and bright globular clusters in dwarf galaxies (I. Georgiev) and a discussion of cold halos and extended clusters in M31 (M. Collins).

Conference summary

An inspiring conference summary was delivered by G. Gilmore. He made a general point that the ΛCDM framework provides a very good description of the Universe from the largest scales down to galaxy size scales, and that, in particular, it describes the initial stages of the Universe very well. He also noted, however, that there are considerable problems with ΛCDM predictions at smaller (galaxy) scales. He argued that a possible avenue towards a reconciliation of theory with the observed Universe at small scales may be less massive (= warm) dark matter particles. He also made the point that in comparison with ΛCDM, the concept of MOND does not provide by itself an adequate description of the Universe as a whole, lacking a cosmological framework. He argued that the internal dynamics of Milky Way satellites within the radius of the Magellanic Stream are likely affected by tidal forces, and advocated caution in the interpretation of dynamical data of objects within that radius. He added that objects in the transition region between galaxies and star clusters — such as UCDs — can give fascinating insights into galaxy transformation processes and massive star cluster formation, while constraints on dark matter properties can only be obtained from objects with sizes above ~100 pc, which he considers as galaxies.

Acknowledgements

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References for figures

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Report on the Workshop

The Evolution of Compact Binaries

held at Hotel San Martín, Viña del Mar, Chile, 6–11 March 2011

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The workshop, organised by ESO and the Universidad de Valparaíso, was held with the aim of bringing together people from different communities to concentrate on the specific problem of binary evolution. Compact binaries divide into many classes, but the evolution of all these objects is driven by a common mechanism: angular momentum loss. From the formation of compact binaries over the various phases of contact to their explosive deaths in a supernova Type Ia or gamma-ray burst, the measurement and understanding of the braking mechanisms was the main discussion point of the meeting.

In order to bring astronomers from the different communities to an understanding of the main problems in the evolution of compact binaries, the workshop began with thorough introductory review talks on the main types of compact binaries,