Report on the ESO Workshop

Central Massive Objects: The Stellar Nuclei – Black Hole Connection

held at ESO Garching, Germany, 22–25 June 2010

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An overview of the ESO workshop on black holes and nuclear star clusters is presented. The meeting reviewed the status of our observational and theoretical understanding of central massive objects, as well as the search for intermediate mass black holes in globular clusters. There will be no published proceedings, but presentations are available at http://www.eso.org/sci/meetings/cmo2010/program.html.

Figure 1. Workshop participants assembled outside ESO Headquarters in Garching.

This workshop brought together a broad international audience in the combined fields of galaxy nuclei, nuclear star clusters and supermassive black holes, to confront state-of-the art observations with cutting-edge models. Around a hundred participants from Europe, North and South America, as well as East Asia and Australia gathered for a three-day meeting held at ESO Headquarters in Garching, Germany (see Figure 1). The sessions were of very high quality, with many very lively, interesting and fruitful discussions. All talks can be found online on the web page of the workshop[1].

The key scientific questions for this workshop were:
- What is the evolutionary/causal connection between nuclear clusters and black holes?
- What can the Galactic Centre tell us about the "nuclear cluster–black hole" connection?
- Where do we stand observationally for black holes, nuclear clusters and intermediate mass black holes?
- What do theoretical models tell us about star formation in the extreme gravitational potential near the black hole and under the extreme stellar densities in galactic centres?
- Do we understand the feeding of the central parsec? How are nuclear clusters replenished with fresh gas?
- What do theoretical models tell us about dynamics, evolution and migration of nuclear star clusters in galaxy centres?
- Are intermediate mass black holes formed in nuclear clusters/globular clusters?
- How do the central massive objects relate to their host galaxies?

In the course of the workshop we walked through these science questions, starting from the best studied example of a supermassive black hole and its surrounding nuclear star cluster, at the heart of our own Galaxy. We indicate the authors of the contributions, which are highlighted in this summary, so that they can be traced in the presentations online[1].

The Galactic Centre black hole and nuclear star cluster

The known orbits of 30 stars around the central radio source in our Galaxy make Sgr A* the best case for a supermassive black hole, with a mass of $4.3 \times 10^6\ M_\odot$ (Stefan Gillessen). Figure 2 shows a fit to the orbit of one of these stars (S2). The supermassive black hole resides in a very massive star cluster of about $3 \times 10^7\ M_\odot$, made up of several populations of stars. The existence of very young O and WR stars in the central few arcseconds around the black hole is puzzling. The currently favoured solution to this paradox of youth is *in situ* star formation in infalling gas clouds. This view is also supported by the fact that the Milky Way nuclear star cluster is rotating (Rainer Schödel). Resonant relaxation can explain the warp and the co-/counter-rotating dichotomy of the young stars (Bence Kocsis). However, the existence of S stars very close to the black hole is even more surprising. These are ordinary B stars with an age of about 10^8 years. Their observed properties can be best explained by a binary disruption scenario, called the Hills mechanism (Alessia Gualandris).

Where is the expected stellar cusp at the Galactic Centre? The formation timescale might be longer than 10^{10} years, i.e. the nuclear cluster is not old enough to have formed a cusp (Holger Baumgardt). The deficit of old stars around Sgr A* could be explained by the collision and destruction of giants with main sequence stars or stellar mass black holes (Melvyn Davies). Another possibility might be that a fraction of the stars get disrupted and accreted onto the central black hole.

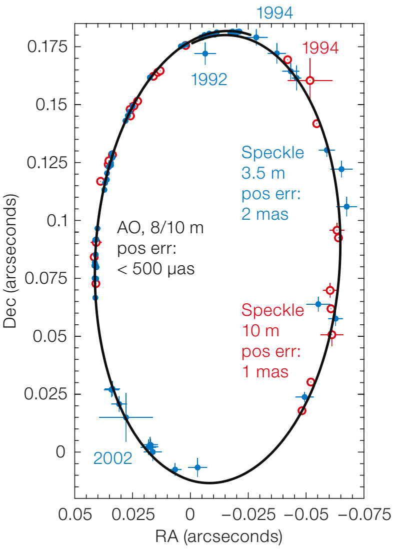

Figure 2. Result of the combined orbit fit for the Galactic Centre star S2. Blue: NTT/VLT measurements. Red: Keck measurements. The black line shows the Keplerian fit (after Gillessen et al., 2009).

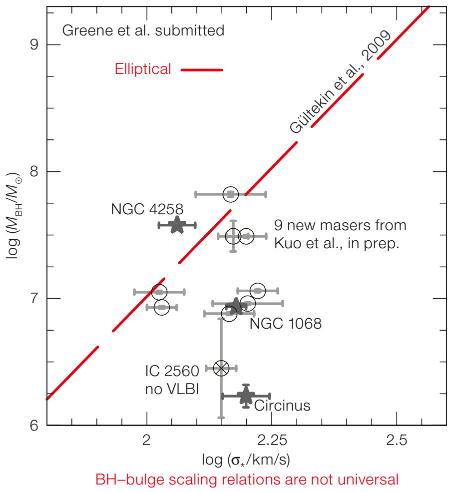

Figure 3. The relation between black hole mass and bulge velocity dispersion is shown for the maser galaxies presented by Greene et al. (2010). The maser galaxies trace a population of low-mass systems whose black holes lie below the M–σ relation defined by elliptical galaxies (red line).

Black holes and their scaling relations

Currently, dynamical black hole mass determinations exist for about 50 galaxies. These correlate tightly with the overall properties of their host galaxy's bulge, e.g., its velocity dispersion σ. However, the low-mass end of the black hole–host galaxy scaling relations is still not well-sampled. Jens Thomas reported on the ongoing SINFONI programme to fill in the underpopulated regions in the M–σ relation using stellar kinematic modelling. Karl Gebhardt pointed out that getting any black hole mass to better than 20 % accuracy is difficult and that taking systematic effects into account is very important. What counts when setting up the scaling relations is the robustness of the assumed uncertainties.

Jenny Greene presented accurate black hole mass determinations in galaxies with megamasers, along with measurements of their stellar velocity dispersion. These galaxies lie below the M–σ relation, showing a large scatter (see Figure 3). Moreover, active galactic nuclei (AGN) diagnostics help to measure black hole masses at the low-mass end. The future for black hole detections looks bright! Upcoming transient surveys may be able to detect many tidal disruption events of stars around low mass black holes (Linda Strubbe).

Nuclear star clusters and their relation to black holes

Nuclear star clusters are very common. They are found in spirals, S0s and dwarf elliptical galaxies with an occupation fraction of about 50–75 %. Nuclear clusters are compact and massive, with half-light radii of typically ~ 3–5 parsec, and masses of 10^6–10^7 $M_\odot$, and they show complex star formation histories (Jakob Walcher). Generally, nuclear clusters are seen in late-type galaxies and black holes in early-type galaxies, but often these two components coincide (Alister Graham). For the nearest nuclear star clusters, the stellar and gas kinematics are spatially well-resolved, and enable the dynamical detection of black holes inside the star clusters (Anil Seth, Nadine Neumayer). Some nuclear star clusters also show signatures of an AGN, making the co-existence of a black hole indisputable (Aaron Barth, Joseph Shields).

Nuclear star clusters observed in nearby (early-type) galaxies (in the Virgo and Fornax clusters) seem to have properties that vary continuously along the luminosity sequence (Laura Ferrarese). Although they represent a tiny fraction of the total light in a galaxy they can be rather prominent above the extrapolation of the outer light profile towards the centre in low-luminosity objects. Nuclear clusters are similar but more compact stellar systems than ultra-compact dwarf galaxies, the latter having comparatively elevated mass-to-light ratios (Michael Hilker). Using spectrographs assisted by adaptive optics, the stellar populations and kinematics of both types of systems can be probed today (Mariya Lyubenova) to test, for example, whether or not they host massive black holes.

Feeding, star formation and feedback

The question of how galaxy nuclei are replenished with fresh gas was discussed on the third day of the conference. There are different mechanisms at work that make gas lose angular momentum and drive it from large to small scales (mergers, bars, unstable gravitational discs, three-armed spirals, turbulent viscosity and magnetic stress), all inferred from observations and simulations (e.g., Francisco Müller-Sanchez, Nozomu Kawakatu). However it is still unclear which mechanism dominates under which circumstances (Witold Maciejewski, Tessel van der Laan, Gaëlle Dumas, Rainer Beck).

Observations show a lag between the central starburst and AGN phase, due to a transition of fast supernova to slower mass-loss winds (Richard Davies). The mass loss from surrounding stars seems to be sufficient to grow a nuclear disc and to cause accretion (Marc Schartmann). We were reminded however that we still do not understand how black holes can be fed (Norman Murray, Rainer Beck), and how AGN feedback works, although a number of scenarios have been studied with detailed numerical simulations (Vincenzo Antonuccio-Delogu, Chris Power). Feedback from star formation could also be an important (and competitive!) contributor in regulating the feeding itself: in the Milky Way it seems to mostly be acting via radiative pressure, but it remains to be seen if this is true also in denser environments near the centre.

Are intermediate mass black holes formed in nuclear/globular clusters?

Theoretically, in young star clusters after core collapse, runaway collisions of stars

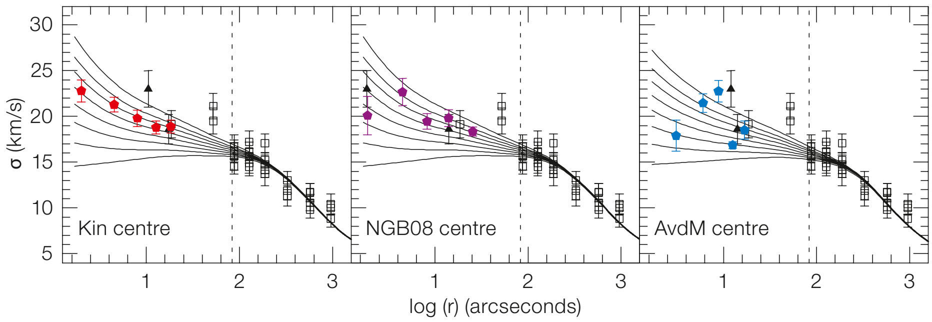

Figure 4. New velocity dispersion (σ) measurements of Omega Centauri shown as a function of radius. The left panel shows the measured σ assuming the kinematic centre, while the middle and right panels show the same for the centre derived by Noyola et al. (2008) and Andersen & van der Marel (2010). The solid lines show isotropic spherical models assuming various black holes masses (0, 1, 2, 3, 4, 5, 6 and 7.5 × 10^4 $M_\odot$). See Noyola et al. (2010) for details.

can result in the build up of massive objects of about 2000 $M_\odot$. However, when including stellar evolution, stellar mass-loss winds limit the growth to a few hundred solar masses (Simon Portegies-Zwart).

Observationally there are a number of signatures for intermediate mass black holes (IMBHs) in globular clusters. Clearly, the most compelling evidence is the detection of non-thermal emission, seen, for example, for G1 in M31, but globular clusters have very little or even no gas and so the emission is very faint or absent.

The evidence from the density structure is still controversial, as the core radius and shallow density slope are not unique signatures for a black hole. These characteristics are influenced by binary heating and are also present around the time of core collapse. However, an IMBH in a globular cluster will suppress mass segregation by scattering the most massive stars, making the quenching of mass segregation a promising tracer to detect IMBHs (Stefan Umbreit, Michele Trenti).

Finally, there are several candidate clusters with suggestive dynamical evidence for an IMBH, e.g., M10 (Giacomo Beccari), M54 (Michele Bellazzini), NGC 6388 (Nora Lützgendorf), and of course, Omega Centauri, for which Behrang Jalali presented new integral field unit kinematics obtained with Argus/FLAMES, supporting the presence of a 4.7 × 10^4 $M_\odot$ black hole (see Figure 4).

Formation of black holes/nuclear clusters

Supermassive black holes observed at $z \sim 6$ are usually assumed to originate either from the remnants of the first stars (Pop III stars, Bernadetta Devecchi), or from intermediate mass black holes with up to ~ 10^5 $M_\odot$. To form massive intermediate mass black holes, the gas in primordial galaxies needs to collapse without fragmenting. Numerical simulations have great explorative power in this context. They enable the influence of different physical processes on the runaway collapse to be studied (Dominik Schleicher), can follow the evolution of complex systems, and moreover constrain the growth by mergers and/or accretion using statistical data on black hole mass, seed distribution and luminosity functions (Sandor van Wassenhove, Silvia Bonoli).

Various scenarios have been proposed to explain the formation of nuclear clusters, and David Merritt detailed some of the important dynamical principles that should be kept in mind while dealing with these. A nearly unavoidable process is the heating of the nuclear cluster if it is dynamically colder than its surrounding stellar environment, but this can be significantly slowed down if a central dark mass is present. David Merritt and Markus Hartmann reviewed the possibility of forming nuclear clusters from infalling (globular) cluster systems, which seems a viable hypothesis, mostly for bulge-dominated galaxies.

Relation to the host galaxy

The question of how the central massive objects relate to the properties of the host galaxy was discussed in the last session of the conference. Peter Erwin pointed out that black holes and nuclear clusters do not seem follow the same scaling relations. While black hole mass correlates tightly with bulge mass (Dimitri Gadotti, Jian Hu), nuclear cluster mass correlates best with total stellar mass, at least in spiral galaxies.

But black hole mass not only correlates with its host galaxy's (bulge) mass, but also with the host galaxy's mid-infrared luminosity (Eleonora Sani) and tentatively also with the number of globular clusters in early-type galaxies (Andreas Burkert). The correlation with globular cluster number even challenges the claim that the M–σ relation is the tightest among the scaling relations (Enrico-Maria Corsini).

The meeting was wrapped up by Ortwin Gerhard in an excellent summary talk that triggered a lively discussion. The topics covered during that week have recently gained quite a lot of momentum both on the theoretical and the observational sides, and the results presented at this meeting provided us with an impressive updated view of nuclear clusters, black holes and their potential links. A number of key presentations also pointed out how much we still have to discover and learn!

Acknowledgements

The success and smooth organisation of this workshop would have not been possible without the help and support of Christina Stoffer, as well as the other members of the LOC (in particular, Behrang Jalali, Davor Krajnović, Harald Kuntschner, Nora Lützgendorf and Svea Teupke). The organisers are most grateful to the SOC for their work and very relevant contributions. We thank the review speakers for their excellent talks introducing the topics, and all speakers for very interesting and enjoyable talks. We are grateful to the ESO education and Public Outreach Department (ePOD) for the beautiful and efficient work in producing the workshop poster and cups.

References

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Links

[1] Workshop programme: http://www.eso.org/sci/meetings/cmo2010/program.html