Reinhard Genzel

Director at the Max-Planck-Institut für extraterrestrische Physik, Garching, Germany

2003 Balzan Prize for Infrared Astronomy

Professor Reinhard Genzel has made fundamental contributions to Infrared Astronomy. He has developed instrumentation which enabled him and colleagues to make outstanding discoveries, including evidence for a massive black hole in the centre of our galaxy.

Institutions Administering Funds:
Max-Planck-Institut für extraterrestrische Physik (MPE)
University of California, Berkeley

Adviser for the Balzan General Prize Committee: Per Olof Lindblad

Cosmic Formation and the Evolution of Galaxies and Massive Black Holes

Research over the past two decades has demonstrated that most large galaxies in the local Universe harbour massive black holes at their centres. In particular, the detailed study of the motions of stars by Professor Genzel's group shows that our galactic centre contains a central black hole a few million times as massive as the Sun, beyond any reasonable doubt. The evidence at the galactic centre is thus now arguably the best evidence for the existence of black holes. The galactic centre has turned out to be an ideal laboratory for testing the black hole paradigm and general relativity in the strong field limit, and for investigating the interaction of a massive black hole with its environment. It has also become clear that most massive black holes had formed early in the evolution of the universe, and that the evolution of the central black holes and the galaxies in which they are embedded are intimately related. The most spectacular examples of these accreting black holes are quasars, which have been discovered at a cosmological redshift corresponding to <1 billion years after the Big Bang.

Professor Genzel's projects supported by Balzan funds were aimed at exploring how this connection came about, what physical processes were involved and when the lo-

cal black hole – galaxy mass relationship was established. They also investigated how massive galaxies like the Milky Way were formed and what the role of galaxy collisions and mergers in the assembly of galaxies was, including the mechanisms leading to the fuelling of the most luminous quasars. This was done by using instruments his team had developed for ground-based, airborne and space telescopes.

The second part of the Balzan Prize was used to strengthen the interaction between the experimental/observational group at the Max-Planck-Institut für extraterrestrische Physik (MPE) and several theoretical and interpretative research groups, in particular, the University of California, Berkeley (USA) and the University of Tel Aviv (Israel), by supporting scientific exchange and providing short-term support for collaborative research, specifically carried out by young scientists.

One major highlight of the research supported in part by the Balzan funds was a new major effort using the MPE-developed SINFONI near-infrared integral field spectrometer (at the ESO-VLT) for the first-ever survey of the kinematics of massive star forming galaxies at redshift ~2, approximately 3 billion years after the Big Bang. This groundbreaking survey, called SINS, has been highly successful and has given key insights into the evolution of stars forming galaxies at that epoch. It has become clear that large and massive disks comparable in mass to the modern Milky Way already existed at that time, but with substantially different physical properties. These recent observations, in conjunction with theoretical work of other groups in Israel and California, have now led to a significant shift in thought on how massive galaxies formed and evolved during this epoch. The SINFONI observations suggest that, rather than major mergers, rapid and continuous accretion of gas from the dark matter halos (the so-called 'cold flows') may have dominated the mass assembly of massive galaxies. This very ambitious and unique survey has just been completed, and has led to the publication of about a dozen papers, including a milestone paper published in *Nature* in 2006 (Förster-Schreiber et al., 2006, 2009; Genzel et al., 2006, 2008, 2009; Nesvadba et al. 2006; Shapiro et al., 2008, 2009; Cresci et al., 2009; Bouche et al., 2007, 2009).

The Balzan funds have also been helpful in providing seed funding for the support of young researchers at MPE, and for stimulating international collaboration. A young scientist, Dr. Natascha Förster-Schreiber, was hired at MPE (in part by Balzan funds), and has now become the leading scientist of the SINS survey. Her outstanding work has attracted world-wide attention. As a result, Dr. Förster-Schreiber won a prestig-

ious Minerva MPG Fellowship (an independent research position funding a small research group for five years) in 2007. In Tel Aviv, a research group led by Professor Amiel Sternberg also carried out active work on this project. The seed funding by the Balzan Foundation led to the award of prestigious Deutsch-Israelische Projektkooperation (DIP) funding by the Deutsche Forschungsgemeinschaft (DFG). The DIP funding allowed MPE-Israel collaboration to include the theoretical group of Professor Avishai Dekel at Hebrew University, Jerusalem.

Balzan funding also supported scientific research and international exchange in galaxy formation/evolution at the University of California, Berkeley, mainly with Professors Christopher McKee and Eliot Quataert, while also including graduate student Kristen Shapiro, who spent part of her time at Berkeley, and part at MPE.

Researchers:
Professor Avishai Dekel
Professor Christopher McKee
Professor Eliot Quataert
Professor Amiel Sternberg

Natascha Förster-Schreiber
Kristen Shapiro

Publications:
Bouché N et al. 2010. The Impact of cold gas accretion above a mass floor on galaxy scaling relations. The Astrophysical Journal. 718: 1001-1018.
Bouché N et al. 2007. Dynamical properties of z ~ 2 star-forming galaxies and a universal star formation relation. The Astrophysical Journal. 671: 303-309.
Cresci G. 2009. The SINS Survey: Modeling the Dynamics of z ~ 2 Galaxies and the High-z Tully Fisher Relation. The Astrophysical Journal. 697: 115-132.
Förster-Schreiber NM et al. 2006. SINFONI integral field spectroscopy of z ~ 2 UV selected galaxies: rotation curves and dynamical evolution. The Astrophysical Journal. 645: 1062-1075, 2006.
Förster-Schreiber NM et al. 2009. The SINS Survey: SINFONI integral field spectroscopy of z ~ 2 star-forming galaxies. The Astrophysical Journal. 706: 1364-1428.
Genzel R et al. 2006. The rapid formation of a large rotating disk galaxy three billion years after the Big Bang. Nature. 442: 786-789.

Genzel R et al. 2008. From rings to bulges: Evidence for rapid secular galaxy evolution at z ~ 2 from integral field spectroscopy in the SINS Survey. The Astrophysical Journal.
Genzel R. 2009. Astrophysics: Galaxies in from the cold. Nature. 457: 388-389.
Nesvadba NPH et al. 2006. Lyman break galaxies under a microscope: the small-scale dynamics and mass of an arc in the Cluster 1E 0657-56. The Astrophysical Journal. 650: 661-668.