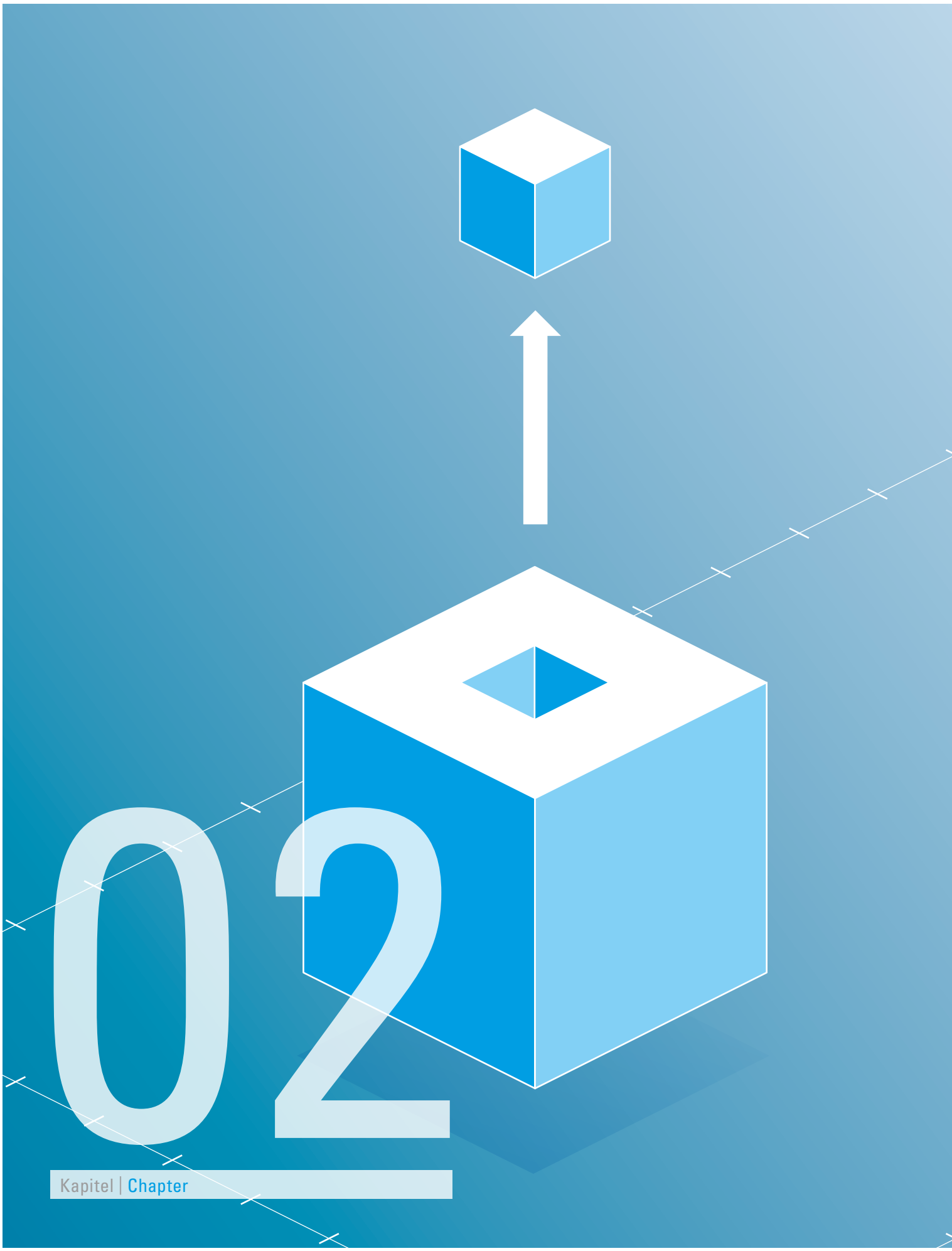

02

Kapitel | Chapter

Forschungsausblick
Research Outlook

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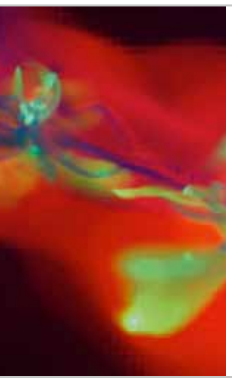
Travelling back in time to the formation epoch of the Milky Way

ISLAND UNIVERSES

When we look up to the sky on a dark, clear summer night (rare in Germany) we see the shimmering band of the Milky Way stretching from horizon to horizon. This is our home in the Universe, a galaxy consisting of approximately one hundred billion stars. Like in most other so called 'disk' or 'spiral' galaxies, most of these stars, with a mass similar to the Sun or somewhat less, live in a fairly thin rotating disk of diameter 60,000 light years. Two or three more stars are formed from the gravitational collapse of dense interstellar gas clouds every year somewhere in that disk, for which reason our Milky Way is considered to be 'actively star forming'. At the center of the disk is a spheroidal concentration of mostly older stars, called the bulge, within which resides a massive black hole of about four million times the mass of the Sun. This structure is typical of most other disk galaxies, even if masses, sizes and the relative proportions of bulge to disk range widely.



EVER SINCE THE DISCOVERY OF GALAXIES AS THE BUILDING BLOCKS OF THE STELLAR EXTRAGALACTIC UNIVERSE ABOUT A CENTURY AGO, THE KEY QUESTION, FOR PROFESSIONAL ASTRONOMERS AND THE INTERESTED PUBLIC ALIKE, HAS BEEN HOW AND WHEN THEY MIGHT HAVE FORMED, HOW THEY HAVE BEEN EVOLVING, AND WHY THERE ARE STAR FORMING DISKS, AS WELL MASSIVE 'DEAD' SPHEROIDS.

Disk galaxies make up most of the more massive star forming galaxies in the current Universe but there are numerous other, amorphous, irregular systems of typically smaller mass, as well as an entire second population of massive spheroidal or elliptical galaxies, with little current star formation. However, while galaxies are the most conspicuous 'island Universes' of light emitting stars, most normal, baryonic matter is actually located outside galaxies, and is in form of very hot, intergalactic plasma. Furthermore, baryons in turn make up only 20% of the matter content in the Universe, the rest is thought to be 'dark matter', which interacts only, or predominantly, via gravity. Dark matter is commonly postulated to be in form of a yet not identified, heavy sub-atomic particle.

Ever since the discovery of galaxies as the building blocks of the stellar extragalactic Universe about a century ago, the key question, for professional astronomers and the interested public alike, has been how and when they might have formed, how they have been evolving, and why there are star forming disks, as well as massive 'dead' spheroids. Although we have at this point only partial, incomplete answers to these questions, there has been a lot of progress over the past two decades. Researchers at several Max Planck Institutes (MPE, MPA and MPIA) have made major and in some cases transformational contributions to that progress, both in terms of experimental work and observation, as well as in theory, numerical simulations and modeling.

BASIC CONCEPTS

From precision measurements of the cosmic microwave background and the large scale structure of galaxy distributions on the one hand, and very large computer simulations on the other, we can broadly understand the formation of galaxies in the 'cold dark matter model'. Local dark matter concentrations ('halos') collapsed by self-gravity in the substrate of the expanding Universe and constituted the locations of baryonic galaxies forming at their cores. These local overdensities are thought to have been already imprinted as quantum fluctuations in the earliest phases after the Big Bang. Theoretical work over the last three decades, pioneered by Simon White and his colleagues at MPA, suggests that baryonic gas present in these dark matter halos was driven inwards in the collapsing halos, and formed concentrations on galactic and sub-galactic scales. Since these baryonic gas concentrations were endowed with an initial angular momentum, the smallest scale of initial collapse was about a tenth of the size of the dark matter halos where the proto-galaxies are expected to form centrifugally supported disks, approximately of the size of modern galaxies. All numerical simulations of large scale structure evolution, such as the large "Millenium Simulation" carried out by Simon White and Volker Springel at MPA, find that large scale structure builds up hierarchically from smaller structures to larger sizes, from smaller mass to larger mass. From the galaxy's perspective, this means that the embryonic galaxy grew over time from gas streams fed from the cosmic 'web', including, from time to time, an incoming smaller galaxy/halo in that stream (a so called 'minor merger'). More rarely (once every 3 Gyrs or so for a massive galaxy), there would also occur a highly dissipative 'major merger', at the end of which two disk galaxies were permanently transformed to a larger spheroidal galaxy.

TAKING TO TIME TRAVEL

Astronomy, unlike physics, but like biology, cannot reconstruct time evolution by active experiments or studies of individuals. Astronomy relies on the determination of the evolution from distribution functions of populations, and on archeolo-

gical evidence of past events still present today, such as the properties of very old stars, or the large scale structure of the Universe. Fortunately, and owing to the finite speed of light and the large size of our Universe, astronomers can also go on time travel backward in time, by using the faint signals of very distant galaxies with big telescopes to observe Milky-Way-mass galaxies when they were still young and in the process of formation. This article tells the story of what we have learned on these time travels.

Cosmological look-back studies of the properties of galaxy populations have revolutionized the empirical knowledge about galaxy evolution over the past two decades. Large surveys have been carried out with broad-band photometry across the electromagnetic spectrum, from X-rays, to the ultra-violet and optical, to the near- and far-infrared, and all the way to the radio bands, exploiting the largest space- and ground-based telescopes available world-wide. The Max-Planck groups at MPIA (Hans-Walter Rix), MPA (the groups of Guinevere Kauffmann and Simon White) and at MPE (my group, and the groups of Ralf Bender, Günther Hasinger and Kirpal Nandra) have been actively engaged in these massive surveys, for instance, with the Sloan Digital Sky Survey (SDSS), with the Very Large Telescope (VLT) of the European Southern Observatory, with the Hubble Space Telescope (HST) and, most recently, with the Herschel far-infrared space telescope of the European Space Agency (ESA). It is now clear that the earliest smallish proto-galaxies formed already 500 to 800 million years after the Big Bang, less than 5% of the current age of the Universe. As expected from the earlier theoretical work, massive galaxies, and in particular massive spheroidal systems appear in larger abundances later, a few Gyrs after the Big Bang, or about 10 Gyrs ago, when galactic star formation activity reached a broad maximum.

Throughout cosmic evolution, most (>95%) of the star forming galaxy population shows a fairly well established near-linear relation between their stellar mass and their star formation rate. The functional form of the relation remains approximately constant and only the ratio of star formation rate to stellar mass, at a given stellar mass, increases rapidly as we look further back in time. Instead of two to three stars per year as in the modern Milky Way, a Milky-Way mass galaxy 10 Gyrs ago formed stars at a twenty times faster rate. Accurate star formation rates unaffected by interstellar dust extinction were most recently provided by the MPE-developed PACS photometer onboard Herschel (PI Albrecht Poglitsch), allowing the first deep look-back surveys in dusty far-infrared bright galaxies led by Dieter Lutz and his colleagues. These findings, along with statistical studies of the spatial clustering and abundances, suggest that star forming galaxies grow in mass mainly from in-situ steady star formation over a period of several Gyrs, rather than from mergers and/or 'starburst' events. A comparison of stellar masses and dark halo masses of galaxy populations, feasible since a few years from a combination of the imaging surveys at different cosmic times and the computer simulations, shows that galaxy formation was an inefficient process throughout that entire cosmic time, converting less than 20% of the available cosmic baryons into stars in galaxies.

FROM GAS TO STARS AND BACK AGAIN

The data and theoretical modeling suggest that galaxy growth at the peak of the formation epoch happened in an equilibrium between baryonic gas accreting onto galaxies and promoting star formation in dense molecular gas clouds, the consumption of gas by star formation, and outflows of gas driven out of galaxies by massive stars through winds and supernova explosions. This concept has recently been tested and confirmed by direct studies of the molecular gas reservoirs in the young galaxies. Linda Tacconi and her collaborators at MPE have observed millimeter wavelength emission lines of the carbon monoxide (CO) molecule, as a proxy of the main constituent of dense, star forming molecular gas, molecular hydrogen, with the Plateau de Bure millimeter interferometer of the CNRS/MPG/IGN Institute IRAM, in the first large survey of cold gas in distant star forming galaxies. They find that their molecular gas contents were about 4-5 times greater than in comparable galaxies in the local Universe, as studied in the COLDGASS IRAM CO survey of Guinevere Kauffmann, Amelie Saintonge and their colleagues. Otherwise the physical processes of star formation in the early Universe seem pretty much the same as in the local Universe. This is exactly as expected in the 'gas regulation model'. While young galaxies were initially provided with large amounts of fresh gas in the dense, early Universe, gas supplies and gas fractions dwindled as the Universe expanded and became more tenuous. In addition, UV and optical observations by several

ALL NUMERICAL SIMULATIONS OF LARGE SCALE STRUCTURE EVOLUTION FIND THAT LARGE SCALE STRUCTURE BUILDS UP HIERARCHICALLY FROM SMALLER STRUCTURES TO LARGER SIZES, FROM SMALLER MASS TO LARGER MASS.

groups, including ours, demonstrate that most of the star forming galaxies 10 Gyrs ago exhibited powerful galactic winds, blasting gas enriched with heavy atoms formed during stellar nucleosynthesis back into the circum-galactic halo and beyond. These winds probably played a crucial role in keeping the efficiency of galaxy formation as low as observed, especially at low galaxy masses.

EARLY DISKS

The time travel method also allows spatially resolved 'in situ' observations of the stellar and gas components within the young galaxies. Adaptive optics assisted integral field spectroscopy on large telescopes, developed in my group at MPE, especially with the SINFONI spectrometer on the VLT (PI Frank Eisenhauer), have for the first time also resolved the ionized gas motions in the young galaxies. From measurements of line of sight velocities from the Doppler shifting of the Hα-recombination line in different parts of these galaxies, Natascha Förster Schreiber and her team have found that more than a third of the young star forming galaxies were rotationally supported disks, as suggested by the earlier theoretical work, although these disks are much clumpier, turbulent and perturbed than the disk of the Milky Way.

A COMPARISON OF STELLAR MASSES AND DARK HALO MASSES OF GALAXY POPULATIONS, FEASIBLE SINCE A FEW YEARS FROM A COMBINATION OF THE IMAGING SURVEYS AT DIFFERENT COSMIC TIMES AND THE COMPUTER SIMULATIONS, SHOWS THAT GALAXY FORMATION WAS AN INEFFICIENT PROCESS THROUGHOUT THAT ENTIRE COSMIC TIME, CONVERTING LESS THAN 20% OF THE AVAILABLE COSMIC BARYONS INTO STARS IN GALAXIES.

QUENCHING

Another remarkable and unexpected finding is that actively star forming galaxies grow only until they hit a 'mass limit', the so-called Schechter mass, which is near the mass of the Milky Way. Throughout cosmic time, galaxies appear to shut down their star formation activity when they reach this limit, and transit to the 'dead' spheroidal galaxy population. The mechanisms responsible for this 'quenching' are currently not understood; it may be caused by a sudden drop in efficiency of gas accretion, cloud or star formation, or an increase in efficiency of gas outflows driven by stars or massive black holes. Because of the implied structural changes from disky to spheroidal morphologies, it is plausible that mergers may also be involved in the process.

WHAT IS THE ROLE OF MASSIVE BLACK HOLES?

Not only the Milky-Way but apparently all other bulged galaxies and spheroids in the local Universe have a central mass concentration that is probably a massive black hole of about one tenth of a percent of the mass of the entire galaxy, as has been shown by surveys co-led by Ralf Bender at MPE. These massive black holes formed at about the same time as their host galaxies. As shown especially clearly in deep X-ray surveys with the NASA Chandra and the ESA XMM observatories (co-led by Günther Hasinger and Kirpal Nandra at MPE), these massive black holes were rapidly growing and luminous at the peak of the massive galaxy formation epoch 10 Gyrs ago. Accreting black holes convert typically ten to thirty percent of the accreted rest mass energy into short-wavelength radiation and into nuclear winds. This astounding efficiency of energy creation may be one explanation for the galactic winds discussed above, and perhaps also for the quenching massive galaxies. It is not clear how black holes of such large masses are formed, since all but $1/10^8$ of the original angular momentum of a gas particle in the disk of a galaxy must be removed for that gas particle to be able to cross the event horizon of a black hole. Mergers have been proposed as one channel of removing angular momentum sufficiently. The large gas fractions of young galaxies might provide another channel, since a marginally stable, gas rich disk naturally has a large internal 'friction' mediated by gravitational torques, and may thus promote efficient internal gas accretion onto nuclei.

THE IMPACT OF MPG RESEARCH IN GALAXY EVOLUTION

Galaxy evolution is a very large and active field of modern astrophysical research, which was, until recently, completely dominated by groups in the United States and the United Kingdom. The powerful facilities and missions offered by ESO and ESA have given European researchers a tremendous opportunity for playing an ever more significant role in this rapidly developing field of research. As I have shown above, the establishment of several well-funded experimental, observational and theoretical efforts at MPA, MPE and MPIA, have placed MPG-research in galaxy evolution at the frontier of the field, across a broad front of approaches.

Image credit: Agertz, O. et al. 2009, Monthly Notices of the Royal Astronomical Society 397, L64

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Cellular chaperones: their role in protein folding and in the genesis of neurodegenerative diseases

1. AT A GLANCE:

Proteins fulfil wide-ranging and vital tasks in all cells. However, to be able to carry out their biological functions, the chain-like molecules must first fold into precisely defined, three-dimensional structures. This complex process is facilitated by special proteins known as 'molecular chaperones'. These essential helpers prevent the erroneous aggregation of immature proteins which can cause Alzheimer's and Parkinson's disease. These age-related neurodegenerative diseases are presently incurable. They pose an enormous medical and social problem, in particular in countries with an ageing population like Germany. Research on the cellular machinery of protein folding as carried out at the Max Planck Institute of Biochemistry can identify new strategies for the treatment of this increasingly important group of diseases.

2. PROTEIN FOLDING AND THE RISK OF AGGREGATION

Proteins support almost all of the cell's vital functions. They are synthesised as chains from the 20 amino acid building blocks on special molecular machines known as the ribosomes. This process is called translation. Human cells contain between 15,000 and 20,000 different proteins, the identity of which is defined by the sequence of their amino acids. The sequence information for a specific protein is stored in our genes, therefore hereditary characteristics take shape on the level of the proteins. Individual protein types vary significantly in terms of the numbers in which they occur per cell. While there are often millions of copies of the proteins that fulfil essential metabolic functions (enzymes), there are often just a few copies of proteins that function as signalling molecules. To be able to perform their wide-ranging biological tasks, newly synthesised protein chains must assume a precisely defined three-dimensional conformation. This process is known as protein folding. It is mainly driven by the property of hydrophobic amino acids to avoid exposure to the aqueous environment of the cell (hydrophobic effect); the amino acid sequence determines the eventual shape of the molecule. Although the protein folding process has been studied intensively by chemists and biophysicists for over 50 years, the fact that cells have so-called molecular chaperones, which help newly synthesised protein chains to fold, only came to light over the past 20 years. These chaperones are proteins themselves and the functions they fulfil are absolutely essential in all types of cell.

The central task of the chaperones is to prevent protein aggregation, that is the clumping of incorrectly folded protein chains. Aggregation is mainly triggered in this context by hydrophobic interactions between not yet folded protein chains and is particularly prominent in proteins with a complex structure (multidomain proteins). The aggregation process is strongly promoted by acute or chronic cellular stress. Acute stress phenomena can be triggered, for example, by elevated temperature due to fever and cause the increased formation of chaperones which accordingly are also referred to as stress proteins or heat shock proteins. In contrast, chronic stress, which is apparently promoted by age-related changes in cells, does not trigger any effective augmentation of the chaperones. Aggregated proteins are not capable of fulfilling their normal biological functions. More importantly, however, they disrupt cellular functions in many different ways (proteotoxicity). Thus, the formation and deposition of aggregates causes neurodegenerative syndromes such as Alzheimer's, Parkinson's and Huntington's disease. Adult-onset diabetes, which, according to recent findings, is related to an age-dependent decline in chaperone activity, also belongs to the group of aggregate deposition diseases.

JUST AS THE HUMAN CHAPERONES OF DAYS GONE BY HAD THE TASK OF PREVENTING THEIR PROTÉGÉS FROM ENGAGING IN UNSEEMLY CONTACTS AND ENCOUNTERS, THE MOLECULAR CHAPERONES PREVENT THE AGGREGATION OF IMMATURE – THAT IS INCOMPLETELY FOLDED – PROTEIN CHAINS BY SHIELDING THEIR EXPOSED HYDROPHOBIC AMINO ACID SEGMENTS.

3. HOW DO MOLECULAR CHAPERONES WORK?

Just as the human chaperones of days gone by had the task of preventing their protégés from engaging in unseemly contacts and encounters, the molecular chaperones prevent the aggregation of immature – that is incompletely folded – protein chains by shielding their exposed hydrophobic amino acid segments. Because these regions are concealed within the interior of the protein after successful folding, the chaperones usually only intervene as long as the folded (native) state has not yet been attained. Thus, the chaperones can distinguish reliably between incorrectly and correctly folded proteins. To ensure productive folding, the chaperones must release their clients, however. This occurs in the course of a precisely controlled reaction which is driven by the energy molecule ATP; in this process the chaperones cooperate with various other factors as part of a large pro-

tein quality control network. Two classes of chaperones are particularly important for the folding of newly synthesised proteins: the components of the Hsp 70 family and the cylindrical chaperonins.

4. TEAMWORK DURING PROTEIN FOLDING

A principal distinction is made between two chaperone functions which contribute critically to the folding of newly synthesised proteins. Small chaperones – which include components like Hsp70 – bind to the nascent protein chains as soon as they emerge from the ribosome. During this phase of biogenesis, the proteins are still structurally incomplete and therefore incapable of folding correctly. It is the task of the Hsp70 chaperones to shield the hydrophobic segments of the nascent chains, thereby preventing their misfolding and aggregation. The Hsp70s combine two functional components, an ATP-binding domain and a protein-binding domain. Access to the protein-binding pocket is controlled by an adjustable latch, the position of which is controlled by the ATP-binding domain. This enables a reaction cycle involving the binding and release of the protein: release allows the protein substrate to bury its hydrophobic areas through folding. If this does not succeed within a few seconds, re-binding to Hsp70 prevents unproductive interactions and suppresses aggregation.

THE CHAPERONINS (HSP60) ARE AMONG THE MOST FASCINATING ATP-DRIVEN MOLECULAR MACHINES. THEY FORM HOLLOW CYLINDERS APPROXIMATELY 15-NANOMETRES (1.5/100000 MM) IN SIZE, WHICH ACCOMMODATE A SINGLE UNFOLDED PROTEIN IN THEIR CENTRAL CHAMBER, AND IN THIS WAY ENABLE IT TO FOLD UNIMPAIRED BY AGGREGATION.

Hsp70 chaperones assume a central role in protein folding in almost all cell types. However, proteins with a particularly high risk of aggregation rely on the additional help of proteins known as chaperonins.

5. SOLITARY CONFINEMENT FOR PROTEINS IN THE FOLDING CAGE

The chaperonins (Hsp60) are among the most fascinating ATP-driven molecular machines. They form hollow cylinders approximately 15-nanometres (1.5/100000 mm) in size, which accommodate a single unfolded protein in their central chamber, and in this way enable it to fold unimpaired by aggregation. This mechanism is best understood for the bacterial chaperonin GroEL and its cofactor GroES; however, very similar chaperonins are at work in all human cells.

GroEL consists of two rings, each containing seven protein units, which are stacked back to back. The ring opening exposes hydrophobic amino acid residues for the binding of unfolded proteins in a manner comparable to sticky fly paper. GroES is a single ring of seven protein subunits, which places itself on the opening of the GroEL ring like a lid. GroES prefers to bind to only one of the rings at a time, specifically the one containing the protein substrate. This step results in the confinement of the bound protein in the GroEL cylinder. The latter then assumes the function of a folding cage which can accommodate protein chains of up to 500 amino acids. The substrate protein remains enclosed for around 10 seconds. Then the cover opens – again in an ATP-regulated reaction – and the folded protein is released into the cell while incompletely folded molecules are again encapsulated and given another opportunity to get into shape.

It is easy to see how this mechanism ensures protein folding while preventing aggregation. The GroEL-GroES chaperonin acts, as it were, as a mini test tube for an individual protein chain. However, the latest studies have shown that this model is incomplete, as the "test tube" is submicroscopic in size and the folding protein is confined into a tiny space. This prompts a change in the energy landscape of the folding reaction whereby the spatial constriction results in the preferential formation of compact forms. The confinement in the folding cage can actually lead to a considerable acceleration of the folding process as compared with folding in a free solution.

6. ROLE OF THE CHAPERONES IN NEURODEGENERATIVE DISEASES

The molecular chaperones work with a variety of other factors as part of a large protein quality control network. Proteases play a particularly important role as their partners. They take the irretrievably misfolded proteins and break them down into their amino acid components. This also helps in the prevention of aggregate formation. However, if this ingenious system, which has been optimised over the course of millions of years, fails, misfolded proteins will accumulate – often with fatal consequences as the misfolding and aggregation of proteins is increasingly identified as the cause of serious diseases. These include, in particular, the aforementioned age-related neurodegenerative syndromes. Their central cytopathological characteristic is the formation of protein aggregates which as-

sume the form of fibrils. These aggregates accumulate inside or outside the neurons in the brain. Their formation is irrevocably associated with toxicity phenomena that ultimately lead to cell death; however, the exact mechanisms underlying aggregate toxicity are not yet fully understood.

Why do these toxic protein aggregates form despite the presence of the chaperones? Resolving this question is the focus of current research as it promises to provide insights that could lead to the development of novel approaches to the treatment of these diseases, which so far have proven incurable. Interestingly, scientists have demonstrated that the chaperones of the Hsp70 family in particular are perfectly capable of preventing pathological protein aggregation. They intervene in the early stage of the process by preventing the so-called nucleation of the aggregates. This is only observed, however, if the chaperones are activated and available in sufficient concentration in the neurons. Therefore, the phenomenon of neurodegenerative aggregation appears to be the consequence of insufficient chaperone capacity. Interestingly, recent findings indicate that the functionality of the chaperones declines during the ageing process. This would explain why the neurodegenerative diseases referred to manifest in an age-dependent manner.

Another key question concerns the mechanisms through which the aggregates trigger cytotoxicity. System-wide approaches implemented with the help of proteomics have yielded new insights into this problem. In particular, scientists from the Max Planck Institute of Biochemistry tested the hypothesis that the aggregates – or their still soluble precursors – prompt other cellular proteins to co-aggregate and in this way impair cellular functions. These studies found that the toxic aggregates actually interact with up to 100 different endogenous proteins. What is important is that the affected proteins fulfil very wide-ranging key functions in the cell regulation process. These include tasks involving the storage and transmission of the genetic material and protein synthesis itself. Consequently, the toxicity of the aggregates is based, at least in part, on their capacity to incite other proteins to aggregate and in this way impair their normal biological function. In addition, the aggregates also damage the molecular chaperones and their partner components, for example by blocking the protein shredders, a particularly perfidious mechanism which disables the cell's defence system.

7. OUTLOOK

How can research on protein folding help in the fight against dementia and similar neurodegenerative syndromes? The importance of the molecular chaperones and their cooperation partners in the prevention of toxic protein aggregation, which has been demonstrated by numerous studies, suggest that ways to activate cellular protein quality control should be sought. The formation of the chaperones is subject to cell regulation mechanisms which can be influenced pharmacologically. That this works in principle has already been demonstrated in cell culture and in model organisms up to the mouse, and biotech companies already exist that focus exclusively on the development of this strategy. However, much work still remains to be done and many hurdles to be overcome until these approaches may reach the clinic. Furthermore, a major challenge consists in decoding the structural characteristics of protein aggregates which give them toxic properties. This will only succeed with the help of an interdisciplinary approach involving the cooperation of physicists, biochemists, cell biologists and neurobiologists. A research alliance of this nature at the Max Planck Institutes of Biochemistry and Neurobiology in Martinsried has recently been selected for funding by the European Research Council.

HOWEVER, IF THIS INGENIOUS SYSTEM, WHICH HAS BEEN OPTIMISED OVER THE COURSE OF MILLIONS OF YEARS, FAILS, MISFOLDED PROTEINS WILL ACCUMULATE – OFTEN WITH FATAL CONSEQUENCES AS THE MISFOLDING AND AGGREGATION OF PROTEINS IS INCREASINGLY IDENTIFIED AS THE CAUSE OF SERIOUS DISEASES.

**RÜDIGER WOLFRUM, EMERITUS SCIENTIFIC MEMBER
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Law's contribution to peace-making

INTRODUCTION

In November 2002, representatives of the two sides involved in the civil war in Sudan – the government of Sudan and the Sudan People's Liberation Movement (SPLM) – met at the Max Planck Institute for Comparative Public Law and International Law in Heidelberg to discuss a peace agreement and interim Sudanese constitution based on general political objectives agreed shortly beforehand. The author, who was Director of the MPI for International Law at the time, chaired these discussions, which included experts from various world regions. The outcome of this three-week conference was an initial draft of a peace agreement and a future constitution that was ultimately incorporated into the constitution of Sudan (the Interim National Constitution) without amendment in parts. This provided for a six-year interim period for Sudan at the end of which a referendum would be held in South Sudan to decide whether it would remain part of Sudan as a whole.

The referendum was held from 9 to 15 January 2011 as planned and resulted in overwhelming support for an independent South Sudan. The secession of South Sudan then took place peacefully and according to schedule on 9 July 2011.

This example proves that legal provisions drawn up with the involvement of all parties concerned can even pave the way for and structure momentous change, such as the secession of part of a state or the Foundation of a new state, and ensure it is achieved peacefully.

Based on this experience, a team from the Max Planck Institute in Heidelberg has advised various states on the reestablishment of their government structures after the end of civil wars or revolutionary uprisings. In addition to issues concerning the organisation of the state, consultations have included a wide range of complex matters, such as electoral law, party law, constitutional law, the establishment of constitutional jurisdiction, the process of law, the protection of human rights, the conclusion of international agreements and their implementation domestically, and administrative law. Participants include ministerial officials, members of human rights committees, members of parliament, judges, practising lawyers and members of constitutional commissions. The consultations are carried out in countries such as Sudan and South Sudan, Afghanistan, Iraq, Somalia, Yemen, Libya and Jordan. The drafting of a peace agreement as part of a three-year project for Darfur with civil society representatives of all parties involved in the on-going conflict is particularly worthy of mention. The draft was presented to the special envoy of the African Union and the United Nations for Darfur and made an important contribution to peace negotiations in Doha. The Doha peace agreement has so far only been implemented on a piecemeal basis, and peace has yet to be fully established in Darfur.

All activities receive third-party funding (German Federal Foreign Office, Norway, EU, UNDP etc.). They build upon the Institute's basic research, and complement and enhance this.

The task of providing consultation for states has been carried out by the Max Planck Foundation for International Peace and the Rule of Law since the beginning of 2013, whereby close academic relationships continue to exist with the Max Planck Institute for Comparative Public Law and International Law. The Managing Directors of this new Foundation are Dr. Daniel Gruss, Dr. Tilmann Röder and Prof. Dr. Rüdiger Wolfrum. Responsibility for providing consultation for specific regions has been assumed by Dr. Daniel Heilmann (Middle East, North Africa) and Dr. Kathrin Maria Scherr (states south of the Sahel region).

PARTICIPANTS

The consulting activities of the Foundation (and previously the Max Planck Institute) are aimed at states in a stage of political transition. This may be for various reasons, which inevitably have an effect upon the nature and content of the consultations. Reasons may include wars lost and the consequent loss of power of the persons or regime in control beforehand (Iraq), internal military conflict after which a new system of government has to be established (Afghanistan, Sudan) and revolutions that have resulted in the removal of existing rulers and their systems (Egypt, Libya, Yemen) or which force existing rulers to base the system of government on the rule of law and democracy (Jordan).

There is generally a lack of the expertise in constitutional and international law required to implement the targeted reforms in all of these cases. Above all, there is insufficient knowledge about how to structure the organisation of the state, which is essentially provided by legal comparison. The expertise in comparative law of the Foundation and also the Institute becomes important here. In the case of South Sudan, for example, it is debatable whether the establishment of a strong centralised state is recommendable for the economic and social development of the state or whether a federal model or decentralisation of state authority would be more appropriate to integrate ethnic and religious groups into the state as a whole. Contrastingly, discussions in the

case of Egypt primarily focus on the relationship of the executive (above all the President) with the legislative, the constitutional relationship between the executive and legislative, the set-up and operation of a constitutional court, the protection of human rights established under international law, the protection of ethnic and religious minorities and the continuation of traditional legal systems, whether based on religious or ethnic principles.

The question of the punishment of crimes committed is mainly raised after the removal of dictators or regimes charged with serious infringements of human rights. There is often conflict between different legal cultural concepts here. In Africa, above all, the emphasis is not necessarily placed on criminal jurisdiction. Traditional forms of victim-perpetrator settlement, such as apology, compensation and the pardoning of criminal punishments, are often favoured. Consultation on this issue has to take the form of dialogue with the parties involved. This aims to take account of both the legal culture that has evolved, as well as international standards and to attempt to harmonise them (see section on Darfur).

FUNDAMENTAL PRINCIPLES OF CONSULTATION AND SUPPORT ACTIVITIES

All consultative and support (primarily training) activities in the recipient states are developed and implemented based on the academic expertise of the Max Planck Foundation in close cooperation with local partners.

This is a key factor, and not just in terms of acceptance of the activity whether consultation or some other kind of support. It in fact reflects a basic principle of international law - the right to self-determination. The latter also includes the right of a state to essentially decide for itself upon the nature and orientation of its structures and national standards. This also applies if the international human rights standards contain provisions for domestic standards.

In particular, this question is raised in its full complexity and in the strongest terms for South Sudan, the youngest state in the international community. Which human rights agreement can and should the new state accede to in light of its cultural and social environment and economic situation? What impact would this have? Members of the government fear, for example, that acceding to the treaty on the elimination of all forms of discrimination against women would have far-reaching consequences for family structures, at least in rural areas. In contrast, women's associations vehemently support accession.

The nature of the Foundation's activities is firstly geared towards the requirements of local partners and takes account of their legal cultures and traditions. The Foundation attaches great importance to maintaining its academic independence in terms of the actual performance of tasks. This is not just respected - the Foundation is in fact held in high esteem on account of this. The work of the Foundation – like that of the Institute before it – is based on the belief that the support of domestic constitutional structures and the creation of effective guarantees to protect human rights make a major contribution not just to the consolidation of a state but also to ensuring world peace. This approach is in line with that of the United Nations whose purpose and objectives are not just to prevent military conflict between states, but also to promote peaceful relations within states and between population groups. This is carried out on the basis of the understanding that major domestic social tension and, in particular, serious infringements of human rights can in themselves jeopardise world peace. This applies even more so in cases where they threaten to destabilise entire regions due to their cross-border impact.

Three examples specifically illustrate the work of the Foundation (or the Institute previously).

ABOVE ALL, THERE IS INSUFFICIENT KNOWLEDGE ABOUT HOW TO STRUCTURE THE ORGANISATION OF THE STATE, WHICH IS ESSENTIALLY PROVIDED BY LEGAL COMPARISON. THE EXPERTISE IN COMPARATIVE LAW OF THE FOUNDATION AND ALSO THE INSTITUTE BECOMES IMPORTANT HERE.

SUDAN/SOUTH SUDAN

The Institute's commitment began with the mediation touched upon briefly at the outset between representatives of the government of Sudan and the Sudanese People's Liberation Movement. Before this mediation work could begin, the Institute held eight workshops in different parts of the country to find out from representatives of civil society and local spokespersons what kind of state structure they hoped for after the civil war, which had already gone on for 20 years. Key issues included the state and religion, the state structure of Sudan as a whole (federalism or decentralisation), self-determination and referendum. The knowledge acquired formed the basis of the *Heidelberg Dialogue*

whose consultations resulted in a draft used in the political discussions in Sudan and which influenced the content of the peace agreement (*Comprehensive Peace Agreement*) and the new national interim constitution. The Institute subsequently advised the South Sudanese government on the establishment of a constitution for South Sudan, which was still a semi-autonomous region of Sudan in its entirety at the time. Members of civil society and representatives of the opposition were also involved in these consultations. The Institute was also consulted by Sudan's government (ministry of justice) on the constitutional court, which was newly established by the constitution.

THE WORK OF THE FOUNDATION – LIKE THAT OF THE INSTITUTE BEFORE IT – IS BASED ON THE BELIEF THAT THE SUPPORT OF DOMESTIC CONSTITUTIONAL STRUCTURES AND THE CREATION OF EFFECTIVE GUARANTEES TO PROTECT HUMAN RIGHTS MAKE A MAJOR CONTRIBUTION NOT JUST TO THE CONSOLIDATION OF A STATE BUT ALSO TO ENSURING WORLD PEACE.

After the entry into force of the national interim constitution and the peace agreement in 2005, the Institute's projects focused on the implementation of the constitutional framework at the request of Sudan and South Sudan. A series of these events were held at the same time for both sides, such as training and information courses on the constitutional court in Khartoum and the supreme court of South Sudan. Consultations were also carried out on matters concerning international law and, towards the end of the interim period, on the organisation and implementation of the referendum.

Many of the training programmes were open to institutions and people in both parts of the country during the transitional period between the entry into force of the interim constitution for Sudan (2005) and the referendum in January 2011, despite the political conflict. From this point, the consultations and training in South Sudan concentrated on the drafting of a new constitution. Immediately after the secession, South Sudan introduced an interim constitution which is now set to be transformed into a definitive constitution. The relationship with Sudan, and how South Sudan is to be integrated into the international community are also key issues. The Max Planck Foundation's expertise in international and public law is also required here. At the same time, this task presents the Max Planck Foundation with the opportunity to directly experience and scientifically analyse the challenges facing a newly founded state in terms of constitution and international law.

AFGHANISTAN

While the Max Planck Institute and later the Foundation were involved in constitutional development in Sudan, which logically resulted in subsequent consulting and training activities, the Institute initially focused more heavily on education and training in Afghanistan. It firstly carried out a consulting project on the development of the Afghan normative system.

After the end of Taliban rule, Afghanistan faced the challenge of establishing a new system of state in line with internationally recognised standards. In particular, the creation of a system of justice and administration based on constitutional principles in accordance with the country's obligations under constitutional and international law is a key requirement in ensuring the peaceful coexistence of the various population groups and long-term political stability.

Since 2004, the Max Planck Foundation (and previously the Max Planck Institute) has been involved in a series of different projects concerning the set-up of constitutional structures by providing academic consulting and training in Afghanistan. Project employees gain a direct insight into the normative traditions, understanding of the law and actual forms of conflict resolution in this heterogeneous society. This is of major importance to basic research.

The projects can be sub-divided into four closely related categories. The first series of projects is aimed at on-going training for judges, public prosecutors and other lawyers in the provinces. Various legal topics, but above all procedural law, are covered. This ultimately seeks to promote appreciation of the protection of human rights amongst the judiciary and consequently prevent human rights infringements by the judicial system. In addition to judges and public prosecutors, the training events are also attended by the defence counsel, police and prison officers, officials from the ministry of women's affairs and representatives of non-governmental organisations. Four thousand people have now attended the courses. This means that a large proportion of the juristic decision-makers in the field of criminal justice have been reached. The second series of projects, which has been running since 2006, focuses on the next generation of Af-

ghan judges with a specially tailored training programme and expert support from the legal faculties. Topics such as constitutional law, fundamental and human rights, judicial organisation, judicial ethics, procedural principles and general and specialised criminal law are covered. The third project series concentrates on the establishment of administrative law for Afghanistan. This complex issue has been neglected to date despite the fact that administrative law is of major importance in the development of a state of law as applied constitutional law. This project concerns the establishment of general administrative law to be enacted as legislation and the consolidation and harmonisation of Afghanistan's fragmented specialised administrative law. The Foundation plays a consultative role. This involves presenting the various options from a comparative law perspective and shortcomings to Afghan legal professionals without defining a specific system. Finally, the fourth series of projects is based on academic activities. This primarily includes academic seminars on topics relating to international constitutional law, such as the reconciliation of Shari'a law with secular law.

The training initiatives are based on handbooks produced by employees on topics such as procedural law, international law and administrative law. These are available in the teaching languages of Dari and Paschto, as well as in English. These works are the only material most lawyers can consult for the finding of justice in the Afghan provinces and districts where there are no libraries. These handbooks are based on Afghan law as far as possible. However, they provide comparison with minimum standards under international law and make reference to regulations in other national legal systems.

The courses are mainly taken by Afghan university lecturers and judges with specific knowledge of Afghan legal practice. They receive intensive preparation based on the handbooks produced by Max Planck academics before deployment.

BEFORE THIS MEDIATION WORK COULD BEGIN, THE INSTITUTE HELD EIGHT WORKSHOPS IN DIFFERENT PARTS OF THE COUNTRY TO FIND OUT FROM REPRESENTATIVES OF CIVIL SOCIETY AND LOCAL SPOKESPERSONS WHAT KIND OF STATE STRUCTURE THEY HOPED FOR AFTER THE CIVIL WAR, WHICH HAD ALREADY GONE ON FOR 20 YEARS.

DARFUR

The third example concerns the Institute's activities in Darfur; these date back to 2006, and have not yet been completed. In collaboration with local partners and with funding from the Max Planck Society and the Foreign Office, the Max Planck Institute has supported internal dialogue with civil society in Darfur in the aim of contributing to a lasting, peaceful resolution to this conflict. During the period 2008-2010, events were held with representatives from the full spectrum of political and social groups in Heidelberg and Khartoum. This dialogue resulted in the *Heidelberg Darfur Dialogue Outcome Document*, a peace agreement and a constitution for the Darfur region which contains three federal states. In order to produce this document, the participants had to jointly identify the reasons for the conflict. In contrast to how the situation is frequently portrayed, it emerged that there was not one single factor. Ethnic rivalries play just as much a part as the complete marginalisation of the Darfur region by the government in Khartoum, changes to living conditions, the breakdown of traditional structures, disputes over resources, the instrumentalisation of specific groups by the government in Khartoum and other factors. The *Heidelberg Darfur Dialogue Outcome Document*, which was drawn up and approved by participants from Sudan under the consultation and guidance of an international team of experts convened by Professor Wolfrum, an Institute working group and Professor Al-Tayeb Haj Ateya (Khartoum), attempted to develop conflict solutions against this background. In contrast to South Sudan, the solution sought was not the secession of the Darfur region from Sudan, but instead its better integration into Sudan. The implementation of this approach would have far-reaching consequences for the state structure in Sudan.

There was primarily contention over the Darfur region's relationship with Sudan, the distribution and usage of land and coming to terms with and punishment of serious human rights infringements committed. The document supports the return to a Darfur state as it existed historically before being divided into three parts by the government in Khartoum for political reasons. This aimed to enhance Darfur's position in a Sudan with a federal structure. The document also favours a return to historical conditions in relation to the distribution and usage of land when it was allocated to tribes or groups who managed it in accordance with certain principles. This would mean Sudan having to revoke "nationalisation" of the land. This proposal was most strongly opposed. The document adopted a new approach to coming to terms with and punishing crimes committed. It focuses on the traditional forms of dispute resolution here but included the International Criminal Court as an authority of last resort in the solution proposal.

IN PARTICULAR, THE CREATION OF A SYSTEM OF JUSTICE AND ADMINISTRATION BASED ON CONSTITUTIONAL PRINCIPLES IN ACCORDANCE WITH THE COUNTRY'S OBLIGATIONS UNDER CONSTITUTIONAL AND INTERNATIONAL LAW IS A KEY REQUIREMENT IN ENSURING THE PEACEFUL COEXISTENCE OF THE VARIOUS POPULATION GROUPS AND LONG-TERM POLITICAL STABILITY.

This document was the first time a proposal had been presented under which civil society in Darfur could and was able to participate in the political debate on the establishment of peace in Darfur, which is supported by the African Union and United Nations. The implementation of this proposal requires the Sudanese government to take part in these methods of resolution.

CONCLUDING REMARKS

The Max Planck Foundation for International Peace and the Rule of Law, and the Max Planck Institute for Comparative Public Law and International Law before it, have made a contribution to the development of national legal systems in various countries and to a better understanding of the rule of law in critical phases through basic research in the fields of international law, foreign public law and comparative law. This had a stabilising domestic effect in specific individual cases. However, these consultative and training activities also enabled Max Planck academics to obtain a direct insight into legal challenges and their resolution during the transformation and establishment of state systems, or even the foundation of states, providing major impetus for basic research.

IN ORDER TO PRODUCE THIS DOCUMENT, THE PARTICIPANTS HAD TO JOINTLY IDENTIFY THE REASONS FOR THE CONFLICT. IN CONTRAST TO HOW THE SITUATION IS FREQUENTLY PORTRAYED, IT EMERGED THAT THERE WAS NOT ONE SINGLE FACTOR.