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编者按:

从飞秒化学获得1999年诺贝尔化学奖,到2023年诺贝尔物理学奖授予阿秒脉冲实验技术,超快过程一直是相关科学家重点关注的热门研究领域。在飞秒尺度下,我们可以跟踪原子核的运动,直接观察化学键的断裂与生产,到了更快的阿秒尺度,我们能直接探测电子的实时运动,从而更深入地理解众多物理、化学以及生物过程的微观本质。在本次访谈中,德国科学院院士Jörn Manz总结了他和山西大学杨勇刚教授十余年在分子超快量子动力学方面的合作成果,包括分子中飞秒尺度的原子核动力学和阿秒尺度的电子动力学的模拟与操控,分析了这些成果对超快领域的影响并对后续相关研究方向以及潜在应用进行了展望,为大家了解超快领域的现状与未来提供了一个很方便的视角。

## 超快分子量子动力学模拟与操控 ——德国科学院院士Jörn Manz访谈录

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**杨勇刚:**尊敬的Jörn Manz教授,从2013年1月到2024年5月,您一直是山西大学物电学院的特聘教授。除了新冠疫情期间外,您每年到山西大学访问两次,每次访问两个月,您在德国的单位是柏林自由大学,那么您如何总结我们之间的合作?山西大学和柏林自由大学的研究专长是如何互补并结合在一起的?在我们的研究领域(即超快分子量子动力学领域,属于2023年诺贝尔物理学奖“阿秒科学”的热门子领域),我们是否取得了一定进展?

**Jörn Manz:**好的,对于这个问题,我不仅需要从科学研究方面,还需要从其他方面来进行回答。

**杨勇刚:**让我们从科学研究开始。我们在超快分子量子动力学领域取得了哪些进展?

**Jörn Manz:**回顾过去,我们在超快分子量子动力学方面取得的进展可归纳为5个紧密联系但各有侧重点的子课题。我将在下面对其进行概述,标注为1—5。有关详细信息,以及对最新技术的深入介绍和最新文献的适当引用,请参阅我们联合发表的文章[1-38],

在此对所有共同作者(即我们的学生和合作伙伴)表示衷心感谢。

在继续之前,先简单说一下参考文献[1-38]有一个共同点,就是其中大部分是由你(杨勇刚)和我合著的,但也有少数例外。特别是有些出版物是我和刘春梅合著的。她在山西大学由你和我共同指导,获得硕士学位。之后,她于2015年9月至2019年7月在Beate Paulus教授、我和Jean Christophe Tremblay博士(现为梅斯洛林大学教授)共同指导下,在柏林自由大学攻读博士学位。她在柏林自由大学期间得到了“柏林自由大学-中国公派留学奖学金(FUB-CSC计划)”的支持。随后,她被南京邮电大学聘用,我下面要介绍的文章列表也包含了她的相关成果。首先我们看第一个子课题。

### 1 分子在阿秒和飞秒时域内的原子核流和电子流

分子或分子离子由原子核和电子组成。我们的

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研究集中于它们在非相对论近似下的量子动力学。为此,通常的做法是为分子波函数求解相应的含时薛定谔方程<sup>[39]</sup>。这样就可以计算出各种分子性质的时间演化。例如,大多数分子量子动力学家,包括我们自己,会计算相应的核和电子的密度随时间演变。进一步,我们计算了核和电子的流密度以及由此产生的核流和电子流。原则上这一研究领域早在1926年就由薛定谔提出<sup>[39]</sup>,但从那时起,这一领域基本处于休眠状态。从2006年开始,我为其复兴做出了贡献<sup>[40]</sup>。我把这一课题从柏林自由大学引入山西大学,进入了一个广阔且尚未深入探究的学术领域,为新的发现提供了很大的机会。你为此提供了重要的量子化学和量子动力学方法,其中包括你自己发展的方法。因此,我们的第一篇合作论文<sup>[1]</sup>提出了双原子分子中核流的四种新的量子效应,其时空分辨率降至 $0.05 \text{ \AA}$  ( $1 \text{ \AA} = 10^{-10} \text{ m}$ )和 $200 \text{ as}$  ( $1 \text{ as} = 10^{-18} \text{ s}$ )。在我们的很多篇后续论文中<sup>[2-4,6-17,23-25,27,29,37]</sup>都发现了在核流和电子流中的更多量子效应。在参考文献[7]中,我们发表了分子核流和电子流的展望。

**杨勇刚:**您认为我们在这个子课题的工作会对超快领域产生什么影响?

**Jörn Manz:**总的来说,它有助于吸引世界各地的其他团体来研究分子中的超快核流、电子流或电子流密度。我们的例子很有启发性,结果表明存在一些分子超快过程,这些过程用传统的密度的方法去分析几乎看不到任何动力学,而只有采用我们的电子流或电子流密度的分析方法才能发现分子的这种超快动力学。接下来我们重点分析电子流。

## 2 分子内阿秒电荷迁移

电子运动可以由核运动引起——这个过程被称为“电荷转移”,参见参考文献[41]。由于重要的核运动通常需要 $10 \text{ fs}$  ( $1 \text{ fs} = 10^{-15} \text{ s}$ )或更长时间,电荷转移也需要 $10 \text{ fs}$ 或更长时间。相反,当原子核被冻结时,电子也可以移动——这个过程被称为“电荷迁移”。1944年,H. Eyring等人预测电荷迁移是指电子从线性分子的一端移动到另一端,再移动回来,这一过程发生在几百阿秒到几飞秒的时域内<sup>[42]</sup>,即比电荷转移快得多,另见参考文献[43]。然而,他们的发现被完全遗忘了。直到1995年,电荷迁移被重新发现,首先是由E. W. Schlag小组进行实验<sup>[44]</sup>,然后是几个小组进行理论工作,最突出的是L. S. Cederbaum<sup>[45]</sup>、F. Remacle和R. D. Levine<sup>[46]</sup>小组的

研究工作,文献调研参见文献[11]。我在柏林自由大学的团队从2006年开始探索这一领域。例如,我们与国际领先的合作伙伴一起发现了环形电荷迁移<sup>[40]</sup>,并发现由于核运动引起电子退相干,电荷迁移通常会在几飞秒内停止<sup>[47]</sup>。2015年,由H. J. Wörner教授联合数个专家的研究组首次将实验和理论结合,重建了HCCI<sup>+</sup>中的电荷迁移,这一进展引起了你和我的关注<sup>[48]</sup>。同样,我将这一概念由柏林自由大学引入山西大学,你提供了计算方法,并与我们的学生一起发现了电荷迁移中的新量子现象<sup>[10-14,21-25,28-29]</sup>,例如由核运动引起电子退相干和复相干,从而导致HCCI<sup>+</sup>中电荷迁移的衰减和部分恢复<sup>[23]</sup>,以及第一个三维效应:螺旋电荷迁移的量子控制<sup>[28]</sup>,与之前的线性(一维)<sup>[12,14,23-25,42-48]</sup>和圆形(二维)现象互补<sup>[10-11,13,40]</sup>。

**杨勇刚:**您对与这一子课题相关的后续研究有什么展望?我们的在这方面的工作对后续研究会发挥什么作用?

**Jörn Manz:**我认为在不久的将来,目前对电荷迁移的基础研究将为相关应用开辟道路。原则上,电子电荷的超快移动可能引起分子键断裂等后续过程<sup>[44]</sup>。对后续进程的控制要求对更基本的电荷迁移过程进行控制。我们的相关工作作为这类控制提供了成功的例子<sup>[24,28]</sup>,比如我接下来要谈到的对称性操控。

## 3 分子对称性破坏与恢复的阿秒操控

对称性破坏是自然界中的一个重要过程,最近的研究见参考文献<sup>[49]</sup>。超短激光脉冲可以破坏分子的电子对称性。我提出了这样一个概念,即通过设计良好的第二束激光脉冲,并以适当的时间延迟发射,可以恢复对称性,从而“消除”第一束激光脉冲的“破坏性”影响。2017年,我访问了我的日本朋友Kenji Ohmori教授在日本分子科学研究所的实验室,通过波包干涉测量法在纳秒精度内得到了这一理论实验结果。在2018年,来自中德日三个国家的科研工作者合作发表了这一开创性的实验和理论成果<sup>[18]</sup>。随后,这一课题在刘春梅博士论文中得到进一步研究,参见参考文献[20-21,26]。此外,我和我的搭档Dietrich Haase教授(柏林自由大学)以及Jean Christoph Tremblay教授(梅茨洛林大学)发现激光脉冲可以在保持原子核对称的同时破坏电子对称性<sup>[49-50]</sup>。

**杨勇刚:**这些都是很根本的理论,预期在将来会衍生出很多应用,您是否已经想到了可能的应用?

**Jörn Manz:** 嗯,让我们考虑一下非手性分子中电子对称性破坏和恢复的情况。对称性破坏使分子具有手性,随后的对称性恢复使其回到非手性状态。因此,该过程将允许超快激光控制非手性分子的瞬态手性,这就涉及我下面要讲的手性翻转问题。

#### 4 激光操控分子在飞秒或阿秒时域的手性翻转

在我们研究电荷迁移<sup>[27]</sup>和操控电子对称性方面的工作过程中<sup>[50-51]</sup>,我们设计了两束圆偏振激光脉冲,打破了定向异核双原子分子(如 NaK 或 RbCs)中电子密度的所有对称元素,使得电子密度具有手性,而原子核保持原来的高对称性( $C_{\infty v}$ )。随后,手性电子密度在两个电子对映体之间翻转。它们两个互为镜像,不能通过旋转相互重叠。手性翻转是周期性的,对于相同圆偏振或相反圆偏振的激光脉冲,手性翻转周期分别在飞秒和阿秒时域内<sup>[30-32]</sup>。这意味着在分子层面实现超快手性翻转的过程中创造了一项新的世界纪录,这一突破为超快光学和分子科学领域打开了新的应用前景,例如超快自旋电子学<sup>[30]</sup>。

**杨勇刚:** 前面的1节到4节确实都是联系紧密的分子超快过程,乍一看似乎各自侧重点也相当多样化。是否存在一个共通的研究课题,能够同时利用前述1到4的多个进展?

**Jörn Manz:** 确实可以,比如我下面要谈到的分子量子操控。

#### 5 分子飞秒/阿秒过程的激光操控

1节到4节中的一部分文献都详细介绍了如何设计合适的激光脉冲制备给定的量子态,这些态可以启动分子和原子中的特定过程<sup>[4-5,11-12,14,18,20-21,24,26,28-32]</sup>。而这些多种多样过程包括杂化轨道的激光操控<sup>[5]</sup>、分子内电子流的操控<sup>[11]</sup>、电荷迁移的产生和操控<sup>[12,24,28]</sup>、电子对称性的破坏和恢复<sup>[18,20-21,26]</sup>、电子手性翻转的产生和操控<sup>[30-32]</sup>。自1986年以来,我被认为是这一研究领域的先驱之一<sup>[52]</sup>,我将该领域从柏林自由大学引入山西大学,而你为此发展了计算所必需的结合量子化学和量子动力学的新方法。我想说你在激光控制和分子模拟方面深厚的专长优势使这些方法能有效地应用到1到4的所有问题中,并将在1到4中积累的经验应用到分子飞秒/阿秒过程的激光操控。

**杨勇刚:** 我们的合作是否推动了超快分子量子动力

学领域以外的其他领域?特别是,我们的合作是否有助于山西大学已经建立起来的一些相关研究领域的进展?

**Jörn Manz:** 这两个问题的答案都是肯定的。一般来说,在基础科学领域,我们总是在自己关注的研究领域中寻找新的发现,突然间,我们意识到其他相关领域也面临着类似的挑战。这样,我们可以把我们原来的研究领域的相关概念和方法,应用到其他领域,比如我下面要谈的6和7这两个例子。

#### 6 超快硼团簇分子转子及核自旋效应

我们在山西大学还开启了物理学院和化学学院的合作,特别是激光光谱研究所和分子科学研究所的跨学科合作。值得一提的是,我们在分子科学研究所的合作伙伴李思殿教授向我们介绍了一种大家非常关注的分子,即平面硼转子,这在柏林自由大学从未被研究过,我们联合发表了一系列成果,参见参考文献<sup>[17,19,34,36,38,53]</sup>。我们首次揭示了这些分子转子的共同机制:它们由一个小分子“内轮”组成,在一个更大的伪旋转的“外轴承”中旋转<sup>[34]</sup>,这里的“伪旋转”意味着轴承并不旋转,而是适应内轮旋转,使其形状看起来好像在旋转,这类似于在伪旋转的笼子中旋转的分子<sup>[54]</sup>,这是我在1980年发现的。这一机制对硼转子产生了巨大的影响,例如,具有相当低对称性的多个等效全局最小结构被统一为具有较高对称性的整体结构。这种机制并不局限于硼转子<sup>[35,38]</sup>。

进一步,我们与 Thomas Grohmann 博士和 Dietrich Haase 教授(柏林自由大学)一起对硼转子的核自旋效应进行了研究。这一效应在之前的众多出版物中并未被考虑到,它可能会与传统的处理方式产生矛盾。特别是,核自旋会禁止全局最小结构的形成<sup>[53]</sup>。因此,不能从全局最小结构出发对分子进行经典动力学模拟。此外,核自旋会阻止激光对分子内旋转的激发作用<sup>[19]</sup>。然而,通过硼转子的同位素取代,我们实现了全局最小结构的布居,随后可以扩展到所有全局最小结构。这一结果构建了从基础量子物理学到现象学热力学的桥梁,即在全局最小结构上的扩散意味着熵的增加,这使人联想到热力学第二定律<sup>[36]</sup>。

#### 7 里德堡原子理论

在山西大学激光光谱研究所的一个非常重要的课题是里德堡态的激光制备和操控,例如重碱金属

原子。李昌勇教授和赵建明教授将我引入这一领域,并且两位教授的博士生王丽梅详细地向我讲解了在实验室的相关实验。我很高兴能在山西大学了解到这一快速发展的研究领域,并为从三能级避免交叉实验测量推导出高激发铯里德堡原子的量子缺陷做出了贡献<sup>[33]</sup>。

**杨勇刚:**在总结我们合作取得的科学成果之后,您能谈谈我们的成果产生的影响吗?

**Jörn Manz:**可以,分子量子动力学领域的全球知名团队都注意到了我们的相关成果,其中有一些概念和想法是我们首次提出并很快被知名实验研究组所验证,推动了领域前沿。另外我想简单地提一下我们的合作得到的部分回报,比如你在此期间晋升为物理学正教授,我们两人都是山西省“百人计划”入选者。另外在2018年,我被评为首届山西特聘专家。

**杨勇刚:**当然,我们的学生和合作伙伴也感受到了合作的回报。事实上,当您来山西大学时,您在柏林自由大学的工作组已经与全球优秀的合作伙伴形成了成功的合作网络。您把那些卓有成效的国际合作网络引入到了山西大学。能谈谈这对我们的合作有什么帮助吗?

**Jörn Manz:**你的问题给了我向合作者表示感谢的机会,在这里我们不仅要向山西大学的学生和合作伙伴表示衷心的感谢,而且如你所提到的,我们也要向我以前在柏林自由大学工作小组的优秀同事以及为我们合作的成功做出贡献的杰出国际合作伙伴表示衷心的感谢!从这些年合作发表的文章列表中可以看到这些合作者的名字,同时我们也在本摘要的末尾对这些合作者表达了感激之情<sup>[1-38]</sup>。我们特别要感谢山西大学的赵建明教授、李昌勇教授、李思殿教授,柏林自由大学的Dietrich Haase教授、Beate Paulus教授和Jean Christophe Tremblay教授(J. C. T.现在是梅斯洛林大学的教授),以及内布拉斯加大学林肯分校的Dennis J. Diestler教授、日本分子科学研究所的Kenji Ohmori教授、赫尔辛基大学的Dage Sundholm教授和中国科学技术大学的严以京教授。多年来,你、李思殿教授、赵建明教授共三个课题组的多名学生,在我们的共同指导下做出了很多重要的工作,包括(以下按姓氏字母顺序排列)陈赟姣、贾东明博士和刘春梅博士(均现就职于南京邮电大学)、裴彬彬(现就职于山东省日照中学)、田文娟博士、王丽梅(现就职于巴贝恩豪森大陆汽车技术有限公司)以及王慧慧博士(现就职于山西大学),王慧慧博士

和你一样,均毕业于Oliver Kühn教授的课题组(我在柏林自由大学的优秀小组成员,现任职于罗斯托克大学)。我们的合作还得到了我在柏林自由大学的前同事的宝贵意见,特别是Ingo Barth博士(现任职于Kreditanstalt für Wiederaufbau)、Tim Bredtmann、Thomas Grohmann (Robert-Blum-Gymnasium)、Gunter Hermann(柏林拜耳公司)、Jhon F. Pe'rez-Torres(现为布卡拉曼加桑坦德工业大学理论化学教授)、Vincent Pohl(Hermes Germany GmbH)、Axel Schild (Digital Identity)和Burkhard Schmidt (Weierstraß-Institut für Angewandte Analysis und Stochastik)。

**杨勇刚:**是的,我也衷心地感谢他们为我们的合作研究做出的这么多宝贵的贡献!

在提问开始,您说不仅需要从科学研究方面,还需要从其他方面来进行回答。您能不能谈谈我们在“科学之外”的一些有意思的事情?

**Jörn Manz:**我们的合作研究不仅推动了超快分子量子动力学领域的进步,而且还为我们在相互尊重的基础上共同生活、了解和学习彼此的文化、规则与传统奠定了坚实的基础。生活在一起——对于我和我的日本妻子三岛悦子(Etsuko Mishima-Manz)来说,意味着要和山西大学校园里大约2万名学生和3 000名教职工共同生活。这是一个美丽的校园,这里有实验室、宿舍、运动场和许多绿化良好的公园,还有学校、超市、医院、保卫处等,就像一个嵌入太原这个拥有500多万居民大城市中的一个小城市。校园以及我的实验室的工作环境极为整洁,这一切得益于那些极具工作热情的街道清洁工和室内清洁女工,她们的努力完全配得上获得奥运会的清洁金牌。多亏了无处不在的保安,让校园也很安全。我和我妻子喜欢住在校园里一个简洁的公寓里,这里与其他同事和学生相邻。在访问山西大学期间,为了丰富生活,我会每天早上慢跑穿过校园,并且还有一个特殊的机会,我可以每天晚上在山西大学音乐系中弹奏一架高质量的三角钢琴。同样地,我的妻子每天下午都可以参加她的太极练习小组。在这里还会充实文化,和学生一起学习中文,让他们当我和我妻子的中文老师。反之亦然,我的妻子向感兴趣的学生教授德语。大家一起,包括学生们、我自己和我的妻子,喜欢阅读阿加莎·克里斯蒂的犯罪小说,通过这样来提高学生的英语水平。

校园生活是由一个传统的钟声开启的,从早上6点起床,到上班,再去教职工餐厅,直到晚上22点

休息。教职工餐厅令人印象深刻,这里供应着大约40种不同的美味佳肴,员工积极性很高,餐厅的一个横幅上写到“今天的学生,明天的世界引领者”。

杨勇刚:您总结的“科学之外”这些事情显然都是正面的。但生活是复杂的。您没有经历过什么困难吗?

Jörn Manz:你说得对。从2013年到2024年这么长一段时间,世界并不总是充满阳光,这是“正常的”,也有一些阴影,比如洗衣机的管子坏了,或者疾病,或者事故。在这种情况下我和我的妻子得到了很多帮助,山西大学的工作人员,特别是汪丽蓉教授,以及医院的专业医生,他们都提供了非常好的帮助,在此表示深深的感谢!

其他困难可能来自中德两国不同的文化、规则 and 传统,这可能产生新的、更好的见解和选择,但同样也可能引起冲突。一个例子是,在山西大学,博士生需要以第一作者身份在高水平期刊上发表一定数量的论文。相比之下,德国没有这样的规定。特别是,我发表的文章都是按照作者姓氏字母顺序排列的,在我这个年纪,我不想打破这个惯例,冲突是显而易见的。当然,我希望支持诸如像王丽梅这样的优秀博士生的职业发展,对于博士生做出重要贡献的工作,博士生应该是当之无愧的第一作者,而不是按照姓氏字母顺序排列。为了解决这个冲突,我遵循中国谚语,即入乡随俗。我同意中国的惯例,例如王丽梅作为第一作者,作为一种妥协和对中国惯例的尊重——但是在这种情况下,我会使用我的中国笔名:Yuan Man。这解释了为什么在Jörn Manz教授的文章列表[1-38]中的文章[1-32]是按姓氏字母顺序排列的,而文章[33-38]则是用Yuan Man按照非字母顺序排序。

杨勇刚:除了在山大学之外,您是否还有在中国其他地方让您印象深刻的经历?

Jörn Manz:谢谢你的关心。确实,我们的科学合作也为我和我妻子了解中国的伟大提供了巨大的机会。你和我以及我们的一些学生多次受到其他大学的专家和同事的邀请,参加多个会议,展示我们的柏林自由大学和山西大学的合作成果。这些访问,加上朋友的邀请和共同的假期,拓宽了我和我妻子对中国的视野,作为一个伟大的国家,这里拥有美丽的风景、城市和5000年的动人历史。我忍不住要添加一个列表,列出我们能在2013—2024年间访问的中国各地,以及感谢我们的东道主:

2013年 合肥(严以京,双丰)游览黄山

2014年 青岛(兰峥岗)和厦门(赵仪)

2015年 北京(由帅志刚组织的第15届国际量子化学大会)

2016年 贵州(严运安)和参观了雷山县的西江苗寨

2017年 西安(第六届国际阿秒物理会议)和丽江(由K. Yamanouchi组织的国际超快强激光科学研讨会)

2019年 合肥(在中国科学技术大学度过两个月,严以京),南京,大连,上海(由仲冬平等组织的第十五届飞秒化学会议),西安(由贾锁堂等组织的量子科学与技术会议)

2023年 杭州(由骆钧炎组织的国际开放量子系统动力学研讨会),北京(李峥),北京(高毅勤,李晨)

2024年 南京(刘春梅),襄阳(李淑娟)

这些访问,以及日常的科学合作,也让我们思考中德或中欧关系的历史。例如,访问青岛让人想起了德国将青岛作为在中国的殖民地的那段黑暗历史篇章——相比之下,今天我们能作为平等的合作伙伴在科学领域合作是多么珍贵的礼物!同样,访问北京展示了众多令人动容的地方,其中包括在鸦片战争中被欧洲人残酷摧毁的圆明园遗址。回顾这段历史,欧洲人来绝对应该感到羞愧,这也是让我和我妻子能理解为什么今天中国必须要强大的众多原因之一,要确保这种屈辱永远不再发生。访问苗族少数民族了解了中国对少数民族的支持和对宗教的宽容。作为基督教徒,我们在实验室里也享受到了这种宽容,例如,我们的中国合作伙伴和学生们尊重我和我妻子访问太原的大教堂,我从不在星期日或基督教节日工作,但当然,如果有必要,我会在其他场合弥补这一点。

杨勇刚:回顾我们长达十余年的合作时光,您能否谈谈您感受到的太原乃至中国在“科研之外”的发展的一些亮点?

Jörn Manz:当然可以。在2013—2024年间,我和我妻子也见证了中国人民生活许多领域的巨大进步,这归功于英明的领导和全体人民的积极参与。提及一些典型的例子:2013年,我们第一次访问太原时,大多数建筑都是通过燃煤供暖,造成了可怕的污染——从我们的公寓,我们每个月大约只有两天能看到太原的山脉。当我们于2024年离开太原时,空气变得清新,燃煤供暖已经被淘汰,我们每个月除了大约两天外,每天都能看到太原的山脉。在2015年,突然之间,所有的出租车都变成了电动车,这展现了中国的技术领导地位上的进步,比包括德国在内的其他“发达”国家提前了好几年。太原的汾河河岸被

转变成了 50 km 长的美丽公园,甚至允许人们在汾河中游泳。之前位于晋阳湖周围的工业区也变成了一个美丽的公园,第一条地铁线路也开通了等等。从太原出访其他城市可以很方便的乘坐高铁,中国的高速铁路系统速度达到 300 km/h——这是当今世界最先进的。

**杨勇刚**:我们的科研合作是否让您在中国交到了朋友?

**Jörn Manz**:是的。生活中,我们合作得到的最为珍贵的礼物之一是朋友之间(甚至拓展到各自的家人)的友谊,包括我和你,以及与我们紧密合作的伙伴李思殿教授、严以京教授等。一些始于博士研究生共同导师的关系最终变成了美好的友谊。因此,前博士生田文娟和她的丈夫项坤邀请我和我妻子参加了他们的两次婚礼仪式之一。在德国,举行两次婚礼仪式是闻所未闻的现象,但我们当然尊重中国的现实情况。无论如何,在这个场合上,他的母亲慷慨地带领我们参观了代县的孔庙和嵌入部分中国长城的古老的雁门关。后来,田文娟和项坤邀请我和我妻子到他们的家乡忻州市忻府区豆罗镇向阳村,对于我们来说,这为我们在太原的生活增添了难忘且丰富多彩的经历。最感人至深的事件,实际上也是我一生中获得的最大荣誉之一,是在 2022 年,王丽梅和她的丈夫 Daniel Stefan 在德国 Maria Laach 结婚,由于新冠疫情,她的父母不能离开中国,因此无法参加婚礼。所以丽梅询问作为她的前博士论文合作指导老师的我是否可以担任代理父亲的角色,参加婚礼。我们相信,作为代理父母和代理女儿及丈夫的友谊将永远持续下去。

**杨勇刚**:大家都赞同这确实是一段美妙的经历。最后您能用一两句话概括一下我们合作的科研成果和科学之外的收获吗?

**Jörn Manz**:最后总的来说,我们的合作为我们的研究领域做出了重要贡献,这是一次丰富的生活体验,不仅对于主要科研人员来说是这样,对于合作伙伴和学生来说也是如此。一句话:一加一的结果远大于二。

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## 附: 英文访谈

### Advances of ultrafast molecular quantum dynamics by cooperation between Jörn Manz and Shanxi University

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**Yonggang Yang (YY):** Professor Manz, dear Jörn: You have been our German guest Professor at the Faculty of Physics of Shanxi University (SXU) in Taiyuan, from January 2013 till May 2024. You have visited us for cooperation twice a year, for two months per visit, except during the Covid19 pandemy.

Your home institute is the Institut für Chemie und Biochemie of the Freie Universität Berlin (FUB). How would you summarize our cooperation? How did the complementary expertises at SXU and at FUB add together? Could we launch new progress in our field of research, i. e. in ultrafast molecular quantum

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dynamics which is a hot field according to the 2023 Nobel prize for physics in attosecond science?

**Jörn Manz (JM):** Well, to answer your questions, there are aspects of science and beyond science.

**YY:** Let us start with the scientific summary. What are the advances and developments that contribute to our field of research?

**JM:** Looking back, we could make progress in ultra-fast molecular quantum dynamics which can be classified as five groups. I shall summarize them below as brief overviews with short introductions, labeled 1) — 5). For the details, and for in-depth-presentations of the state-of-the-art with proper quotations of the literature, let us refer - with sincere gratitude to all coauthors, i. e., to our students and partners - to our joint publications [1-38].

Before proceeding, I would like to point to a specialty of those references [1-38]. Most of them are co-authored by You (Y. Y.) and by me (J. M. / Y. M.), but there are few exceptions. Some publications are coauthored by ChunMei Liu and by me. She obtained her master's degree as your student at SXU, co-advised by me. On this basis she worked for her PhD at FUB, guided by Professor Beate Paulus and again co-advised by me and by Dr. Jean Christophe Tremblay (now Professor at the Université de Lorraine, Metz), from Sept. 2015 till July 2019. For three years, her work at FUB was supported by the "Freie Universität Berlin - China Scholarship Program for Doctoral Researchers (FUB-CSC Program)". Subsequently she was called to her present position at the Nanjing University of Posts and Telecommunication (NJUPT). Her scientific results during 2013—2024 are quoted here as integral contributions to our cooperation.

### 1) Nuclear and Electronic Currents in the femtosecond and attosecond timescales

Molecules and molecular ions consist of nuclei and electrons. Our cooperation focused on their quantum dynamics in the non-relativistic regime. For this purpose, it is common practice to solve the corresponding time-dependent Schrödinger equation for the molecular wavefunction<sup>[39]</sup>. This allows to calculate the

time evolutions of all kinds of molecular properties. For example, most molecular quantum dynamicists, including ourselves, evaluate the time evolutions of the corresponding nuclear and/or electronic densities. In addition, we calculated the nuclear and/or electronic flux densities and the resulting intramolecular fluxes or currents. This field of research was opened already by E. Schrödinger in 1926<sup>[39]</sup>, but since then it had been left more or less in a state of sleeping beauty. From 2006 on, I (J. M.) contributed to its renaissance<sup>[40]</sup>. I imported the topic from FUB to SXU, leading into rather large domains of unexplored territory of research, with great opportunities for new discoveries. You (Y. Y.) provided state-of-the-art quantum chemical and quantum dynamical methods for this purpose, including methods developed by yourself. Thus, our first joint publication<sup>[1]</sup> presented four new quantum effects of the nuclear fluxes in diatomic molecules, with spatiotemporal resolutions down to 0.05 Å (1 Å = 10<sup>-10</sup> m) and 200 attoseconds (1 as = 10<sup>-18</sup> s.). Additional quantum effects in nuclear and electronic flux densities of fluxes/currents were discovered in each of our sequel papers<sup>[2-4, 6-17, 23-25, 27, 29, 37]</sup>. In Ref. [7], we presented a perspective.

**YY:** What do you think is the impact of our work in this sub-field?

**JM:** In general, it contributed to attracting other groups world-wide to investigate nuclear and electronic flux or current densities in molecules. Our examples are stimulating. They show that flux or current densities allow discoveries of molecular processes which are hardly obvious, or even not obvious from traditional considerations of the complementary densities.

### 2) Attosecond Electronic Charge Migration

Electronic motions can be induced by nuclear motions- this process is called "charge transfer", see e. g. Ref. [41]. Since significant nuclear motions take typical times of 10 femtoseconds (1 fs = 10<sup>-15</sup> s) or longer, charge transfer also takes 10 fs or longer. In contrast, electrons can also move when the nuclei are frozen- this process is called "charge migration". Charge migration was predicted by H. Eyring et al. in 1944 as a process where electronic charge moves

from one end of a linear molecule to the opposite end, and back, in the time domain from few hundred as to few fs<sup>[42]</sup>, i. e., much faster than charge transfer, see also Ref. [43]. Their discovery was, however, entirely forgotten. In 1995, charge migration was re-discovered, first experimentally by the group of E. W. Schlag<sup>[44]</sup> and then theoretically by several groups, most prominently by the groups of L. S. Cederbaum<sup>[45]</sup> as well as F. Remacle and R. D. Levine<sup>[46]</sup>; for a survey of the literature, see Ref. [11]. My group at FUB started to contribute to this field in 2006. For example, we discovered circular charge migration<sup>[40]</sup>, and together with leading international partners, we also discovered that charge migration is stopped by electronic decoherence induced by nuclear motions, typically within few fs<sup>[47]</sup>. In 2015, the first joint experimental and theoretical reconstruction of charge migration, specifically in  $\text{HCCI}^+$ , by an international team of experts coordinated by H. J. Wörner, put you and me on an alert<sup>[48]</sup>. Again, I (J. M.) imported the concepts from FUB to SXU, you (Y. Y.) provided the methods, and together with our students, we discovered new quantum phenomena in charge migration<sup>[10-14, 21-25, 28-29]</sup>, e. g. decay and partial revivals of charge migration in  $\text{HCCI}^+$  by electronic de- and recoherences induced by nuclear motions<sup>[23]</sup>, or quantum engineering of helical charge migration as the first three-dimensional (3D) effect<sup>[28]</sup>, complementary to the previous linear (1D)<sup>[12, 14, 23-25, 42-48]</sup> and circular (2D) phenomena<sup>[10-11, 13, 40]</sup>.

**YY:** What type of developments do you expect for this sub-field? How could this profit from our contributions?

**JM:** I expect that soon, the present fundamental investigations of charge migration will open the path to applications. In principle, the ultrafast shift of electron charge may induce sequel processes such as molecular bond breaking<sup>[44]</sup>. Control of the sequel processes calls for control of the underlying primary processes. Our discoveries provide encouraging examples of this type of control<sup>[24, 28]</sup>.

### 3) Attosecond Control of Symmetry Breaking and Restoration

Symmetry breaking is an important process in na-

ture; for a recent survey, see Ref. <sup>[49]</sup>. Electronic symmetry breaking in molecules may be induced by an ultrashort laser pulse. I (J. M.) developed the concept that subsequently, symmetry can be restored by a well-designed second laser pulse, fired with proper time delay, which should “heal” the “destructive” effects of the first laser pulse. A fascinating visit to the laboratory of my Japanese friend, Kenji Ohmori, at the Institute of Molecular Science in Okazaki in 2017 stimulated the experimental realization of this concept by means of wavepacket interferometry, with precision of few as during few nanoseconds ( $1 \text{ ns} = 10^{-9} \text{ s}$ ). In 2018, this pioneering experimental and theoretical achievement was published as a collaborative effort by researchers from China, Germany, and Japan<sup>[18]</sup>. Subsequently, the topic was developed during ChunMei Liu’s PhD thesis, cf. Refs. [20-21, 26]. Moreover, together with my partners, Professors Dietrich Haase (FUB) and Jean Christoph Tremblay (Université de Lorraine, Metz) I discovered that laser pulses can break electronic symmetry while conserving nuclear symmetry<sup>[50-51]</sup>.

**YY:** These are fundamental processes. Have you already thought of an application?

**JM:** Well, let us consider the scenario of electronic symmetry breaking and restauration in an achiral molecule. Symmetry breaking makes the molecule chiral, subsequent symmetry restauration brings it back to achirality. Accordingly, the process would allow ultrafast laser control of transient chirality in achiral molecules. This brings me to the next sub-field.

### 4) Flips of Electronic Chirality in the Femto-second or Attosecond Time Domains

As subsidiary result of our work on charge migration (specifically Ref. [28]) and on electronic symmetry breaking<sup>[50-51]</sup>, we designed a set of two co-incident circularly polarized laser pulses which break all symmetry elements of the electronic density in oriented heteronuclear diatomic molecules such as NaK or RbCs. Consequently, the electronic density is chiral, whereas the nuclei conserve their original achiral symmetry ( $=C_{\infty v}$ ). Subsequently, the electronic chirality

flips between two versions called “electronic enantiomers”. These are mirror images which cannot be mapped on each other by rotations. The chirality flips are periodic. For laser pulses with the same or with opposite circular polarities, the periods are in the femtosecond and even in the attosecond time domains, respectively<sup>[30-32]</sup>. This means a new world record in ultrashort chirality flips in molecules, opening new applications e. g. for ultrafast spintronics<sup>[30]</sup>.

**YY:** On first glance, the subfields 1)–4) appear rather diverse. Is there any common theme such that progress in one subfield can profit from progress in the other subfields?

**JM:** Certainly, for example, the molecular quantum control that I am about to discuss.

#### 5) Laser control of molecular femtosecond/attosecond processes

A common theme of several publications in topics 1)–4) is the design of laser pulses for the preparation of target states which initiate specific processes in molecules and atoms<sup>[4,5,11,12,14,18,20,21,24,26,28-32]</sup>. The rather large diversity of these processes include laser sculpting of hybrid orbitals<sup>[5]</sup>, control of intramolecular electronic fluxes<sup>[11]</sup>, induction and control of charge migration<sup>[12,24,28]</sup>, breaking and restoration of electronic symmetry<sup>[18,20-21,26]</sup>, induction and control of electronic chirality flips<sup>[30-32]</sup>. I (J. M.) am considered as one of the pioneers of this general field of research since 1986<sup>[52]</sup>. I imported the field from FUB to SXU, while You (Y. Y.) contributed the necessary state-of-the-art methods of quantum chemistry and quantum dynamics, for this purpose. I would say that your enormous expertise in laser control has enabled efficient transfer of the methods to the benefit of all subfields.

**YY:** Did our cooperation advance other subfields, beyond the domain of the original target, ultrafast molecular quantum dynamics? Did it contribute to progress in the domains of research which were already well established at SXU, beyond any experience at FUB?

**JM:** The answer to both questions is “yes”. It may always happen in fundamental science that we seek new discoveries in our designated field of research,

and out of a sudden, we recognize analogous challenges in neighboring fields. We may then be able to transfer concepts and methods from our original field of research to advance the neighboring field. Our cooperation has two examples which are added here as items 6) and 7).

#### 6) Boron Rotors and Effects of Nuclear Spins

Our cooperation at SXU also opened interdisciplinary projects of the faculties of physics and chemistry, specifically of the institutes of laser physics and molecular science. Our partner at the IMS, Professor Si-Dian Li, introduced us to a fascinating class of molecules, i. e. the planar boron rotors; they had never been investigated at FUB. This led to a series of joint publications<sup>[17,19,34,36]</sup>, see also Refs. [38] and [53]. We unraveled the mechanism of these molecular rotors: They consist of a small molecular “inner wheel” which rotates in a larger pseudo-rotating “outer bearing”<sup>[34]</sup>. Here “pseudo-rotation” means that the bearing does not rotate, rather it adapts to the rotating wheel such that its shape appears *as if* it rotates. This discovery was motivated by the analogous effect of rotating molecules in pseudo-rotating cages which I had discovered back in 1980<sup>[54]</sup>. It has enormous consequences for the boron rotors e. g. multiple equivalent global minimum structures with rather low symmetry are unified to an overall structure with higher symmetry. The mechanism is not restricted to boron rotors<sup>[35,38]</sup>.

Together with Dr. Thomas Grohmann and Professor Dietrich Haase (FUB), we added investigations of the effects of the nuclear spins of the boron rotors. This property had never been considered before, and it led to consequences which conflicted with traditional approaches. In particular, the nuclear spins forbid the formation of the global minimum structures<sup>[53]</sup>. Consequently they forbid standard molecular dynamics simulations which start from global minimum structures. Moreover, they block laser ignition of intramolecular rotations<sup>[19]</sup>. Transient populations of global minimum structures are enabled, however, by isotopic substitution of the boron rotors, with subsequent spreading over all global minimum structures. This

prediction provides a bridge from fundamental quantum physics to phenomenological thermodynamics, i. e., the spreading over global minimum structures implies increase of entropy which reminds of the second law of thermodynamics<sup>[36]</sup>.

## 7) Theory for Rydberg Atoms

A very important topic at the Institute of Physics at SXU is the laser preparation and manipulation of Rydberg States e. g. in heavy alkali atoms. Professors ChangYong Li and JianMing Zhao introduced me (J. M.) to this field, and their Ph. D. student Limei Wang graciously explained the experimental implementation in the laboratory to me. I was glad to learn about this highly developed field of research at SXU, and to contribute to the deduction of the so-called quantum defect for the Stark map of highly excited Cesium Rydberg atoms from the experimental measurement of three-level avoided crossings<sup>[33]</sup>.

**YY:** At the end of this summary of the scientific achievements of our cooperation, can you say something about the recognition of our joint work?

**JM:** Well, worldwide leading groups in the field of molecular quantum dynamics are aware of our contributions. I would also like to mention modestly that our cooperation was recognized with some honors. You (Y. Y.) were promoted as a full professor in physics. Both of us (Y. Y. and J. M.) were fellows of the “Hundred Talent Program of Shanxi Province”. In 2018, I (J. M.) was honored as Distinguished Expert of Shanxi Province.

**YY:** Of course, this recognition is shared with our students and partners. When you arrived at SXU, you already had successful cooperations of your workgroup at FUB with excellent partners worldwide. You “imported” those fruitful international relations to Taiyuan. How did this support our cooperation?

**JM:** Your question is a good reason to express sincere thanks not only to our students and partners at SXU but also, as you suggest, to excellent coworkers of my former workgroup at FUB and to outstanding international partners who contributed to the success of our cooperation. Their names are obvious from the list of joint publications which is given with ex-

pression of gratitude at the end of this summary<sup>[1-38]</sup>.

We would like to acknowledge in particular the stimulating and fruitful impact of Professors JianMing Zhao, Chanyong Li and most notably Si-Dian Li at SXU, Professors Dietrich Haase, Beate Paulus and Jean Christophe Tremblay at FUB (J. C. T. is now Professor at the Université de Lorraine, Metz), and Professors Dennis J. Diestler (University of Nebraska, Lincoln), Kenji Ohmori (Institute of Molecular Science, Okazaki), Dage Sundholm (University of Helsinki, Helsinki) and YiJing Yan (University of Science and Technology of China, Hefei). Over the years, several students and coworkers of your workgroup, and also of the workgroups of Si-Dian Li and JianMing Zhao, co-advised by me, made valuable contributions, including (in alphabetical order) YunJiao Chen, Drs. DongMing Jia and ChunMei Liu (both are now at the Nanjing University for Posts and Telecommunications), BinBin Pei (now at Rizhao high school, Shandong), Drs. Wen-Juan Tian, Limei Wang (now at Continental Automotive Technologies GmbH, Babenhausen) and more recently HuiHui Wang who, like yourself graduated in the group of Professor Oliver Kühn (formerly a distinguished group member at FUB, now at the University of Rostock). Our cooperation also profited from valuable contributions from my former coworkers at FUB, notably by Drs. Ingo Barth (now at Kreditanstalt für Wiederaufbau, Frankfurt am Main), Tim Bredtmann, Thomas Grohmann (Robert-Blum-Gymnasium, Berlin), Gunter Hermann (Bayer AG, Berlin), Jhon F. Pérez-Torres (now Professor of Theoretical Chemistry at the Universidad Industrial Santander, Bucaramanga), Vincent Pohl (Hermes Germany GmbH, Berlin), Axel Schild (Digital Identity, Zürich) and Burkhard Schmidt (Weierstraß-Institut für Angewandte Analysis und Stochastik, Berlin).

**YY:** Yes, I have sincerely expressed my thanks to them for so many valuable scientific contributions.

Now, at the beginning of this summary, you said “there are aspects of science and beyond science.” What is your summary of our cooperation “beyond science”?

**JM:** Our Chinese-German cooperation did not only contribute to the development of ultrafast molecular

quantum dynamics. It also provided the basis for living together, and for learning about the different cultures, rules and traditions, with mutual respect. Living together- for me (J. M. ) and my Japanese wife, Etsuko Mishima-Manz (E. M. -M. ), this meant to share life with 20 000 students and about 3 000 teachers, staff and personnel on the campus of SXU. It is a beautiful campus, with laboratories, dormitories, sport fields, and a lot of green parks, with a school, supermarkets, a hospital, a police station etc. Like a small city embedded within the large city of Taiyuan, which has a population of over 5 million. The campus and my (J. M. 's) workplace in the laboratory were extraordinarily clean, thanks to highly motivated crossing-sweepers and room-cleaning-ladies who would win the gold medal in Olympics for cleaning. The campus is also safe, thanks to the omnipresent police and to the guards. We enjoyed staying in a convenient apartment on the campus, neighboring to the other colleagues and to the students. As contributions to the richness of life during the visits to SXU, I (J. M. ) could do my jogging tour through the campus every morning, and as a special privilege, I could play one of the grand pianos of SXU's great music faculty every evening. Likewise, my wife could join her group of Tai Chi exercises every afternoon. Cultural enrichment included learning Chinese language, together with the students as our teachers. Vice versa, my wife taught German language to interested students. Together, we - the students, myself and my wife - enjoyed reading Agatha Christie's crime stories to advance the students' level of English.

Life on campus is structured by a conventual gong, from the call to get up at 6 h via the calls to work and to the Mensa canteens, till night's rest at 22 h. The Mensa canteens are formidable, with about forty different tasty offers and highly motivated personnel who like to serve the "students today who will be the leaders tomorrow", as it was written on one of the banderols inside the Mensa.

**YY:** This part of your summary "beyond the science of our cooperation" is clearly positive. But life is complex. Have you ever experienced any difficulties?

**JM:** You are right. During such a long time, from

2013 to 2024, it is "normal" that the world is not always full of sunshine, but there are also times of shadows such as a broken tube of the washing machine, or diseases, or accidents. On such occasions, my wife and I could experience - with lots of gratitude! - wonderful and perfect help from the staff at SXU, notably by Professor LiRong Wang, and by professional doctors at various hospitals.

Other difficulties may arise from the different cultures, rules and traditions of our countries, China and Germany. They mutually open their eyes to new and better options, but naturally, they may also cause conflicts. One example is that at SXU, publications are ranked by three categories of excellent, medium and low quality of the journals. A PhD student should publish at least three papers as first author, in a medium or high ranked journal. In contrast, there are no such "Chinese" rules in Germany. Specifically, my (J. M. 's) list of publications is in alphabetical order of the authors, and at my age, I did not want to break this rule. The conflict is obvious: Of course, I wanted to support the career of excellent PhD students such as Limei Wang, but then she should be the well-deserved first author - in non-alphabetical order. To solve this conflict, I followed the Chinese proverb that if you enter a village, then you should adapt the rules of the village. I agreed to the "Chinese" rules, for example with Limei Wang as first author, but as a compromise and expression of the respect of the "Chinese rules" - in such case I would use my Chinese pseudonym, Yuan Man (Y. M. ). This explains why the list of joint publications [1-38] has items [1-32] in J. M. 's alphabetical order, whereas items [33-38] are with Y. M. in Chinese non-alphabetical order.

**YY:** Should your summary of the "beyond science" part of our cooperation include your experiences beyond SXU in Taiyuan?

**JM:** Thank you for asking. Yes, our scientific cooperation also opened great opportunities to learn about the greatness of China. Together (J. M. and Y. Y. ) we and several times also some of our students were invited by leading experts and colleagues at several other Universities, and to several conferences, to present

lectures on our joint FUB-SXU discoveries. These visits, complemented by invitations by friends and by joint vacations, widened my and my wife's views of China as a great Country, with beautiful landscapes, cities and moving history of 5 000 years. I cannot resist the temptation to add a list of the places in China which we could visit during 2013—2024, with the names of the hosts added in brackets, with gratitude:

**2013** Hefei, (YiJing Yan, F. Shuang) and visit to the yellow mountains

**2014** Qingdao (Zhengdan Lan) and Xiamen (Yi Zhao)

**2015** Beijing (International Congress of Quantum Chemistry organized by J. Liu, Z. Shuai)

**2016** Guizhou (Yun'an Yan) and visit to Xijiang Miao village in Leishan

**2017** Xi'an (6<sup>th</sup> International Conference on Attosecond Physics organized by Z. Wei and Z. Chang) and LiJiang (International Symposium on Ultrafast Intense Laser Science, organized by K. Yamanouchi)

**2019** Hefei (two months at the University of Science and Technology of China, YiJing Yan), Nanjing, Dalian (Z. Sun), Shanghai (15th Conference on Femtosecond Chemistry, organized by D. Zhong et al.), Xi'an (Conference on Quantum Science and Technology, organized by S. Jia et al.)

**2023** Hangzhou (International Symposium on Open Quantum System Dynamics, YiJing Yan), Beijing (Zheng Li) and again Beijing (Y. Gao and C. Li)

**2024** Nanjing (ChunMei Liu), XiangYang (Shujuan Li)

These visits, together with every day's scientific cooperation, also led to think about the history of Chinese German or Chinese-European relations. For example, the visit to Qingdao reminded us of the dark chapter of history when Germany took Qingdao as a colony in China – by comparison, what a gift is it that today we can cooperate in science as equal partners! Likewise, the visits to Beijing showed, among many other heart-moving places, the ruins of the emperor's castle which were brutally destroyed by Europeans during the Opium wars. In retrospect, this is absolutely ashaming to Europeans, and one of many reasons to understand that today, China must be strong such that this type of degradation will never

happen again. The visit to the minority of the Miao people confirmed China's support of minorities and tolerance of religions. As Christians, we enjoyed this tolerance also in the lab, e. g. our Chinese partners and the students respected that we (J. M. and E. M.) would visit Taiyuan's cathedral, and I would not work on Sundays or on Christian holidays, but of course I would compensate this on other occasions.

**YY:** Looking back to the time of our cooperation in Taiyuan, could you point to some highlights of the developments “beyond science” here and elsewhere in China?

**JM:** Well, during 2013—2024, my wife and I could also witness enormous progress in many areas of life in China, pointing to wise leadership and enthusiastic realizations. To mention some characteristic examples: When we visited Taiyuan for the first time in 2013, most buildings were heated by coal causing horrifying pollution- from our apartment, we could not see Taiyuan's mountains except perhaps two days per month. When we left Taiyuan in 2024, the air was clean: Heating by coal had been abandoned, and we could see the mountains every day except perhaps during two days per month. In 2015, out of a sudden, all taxis were electro-cars, pointing to China's technological leadership, several years ahead of other “leading” countries including Germany. Taiyuan was connected to China's rapid (velocities till 300 km/h!) railway system- the greatest worldwide. The riverside of Taiyuan's Fenhe river was transformed into 50 km of beautiful parks, even inviting us to swim in Fenhe river. The previous industrial area around Lake Jinyang was also transformed into a beautiful park. The first underground line was opened, and so on.

**YY:** Did our scientific cooperation allow you to make friends in China?

**JM:** Yes. One of the most precious gifts in life which were triggered by our cooperations are personal friendships including the families, naturally between us (J. M. and Y. Y.; we spent a week of holidays on Hainan insula together!) and between me and the very close partners, Si-Dian Li and YiJing Yan. Some of the relations which started as professional co-advisor of Ph. D. students ended up as wonderful friendships. Thus, former Ph. D. student WenJuan

Tian and her husband Kun Xiang invited us (J. M. and E. M. -M. ) to one of their two wedding ceremonies. In Germany, we have never heard of such things as holding the wedding ceremony twice, yet we respect the reality in China. Anyway, on this occasion, his mother generously guided us to KongZi Temple at Daixian and to the ancient Yanmen Guan fortress which is embedded in part of Chinese Wall. Later, the dear Tian and Xiang families invited us to their home city, Xinzhou and even to their home village Xiangyang. For us, this contributed to the unforgettable richness of our lives at SXU in Taiyuan. The most heart-moving event and in fact one of the biggest honors which I ever received in my life happened in 2022 when Limei Wang and her husband Daniel Stefan married in Maria Laach, Germany. During the covid19 pandemic, her parents were not allowed to leave China, hence they could not attend the wedding. So, Limei asked me as her former PhD thesis co-advisor whether he could take the role as vice-father, for the wedding. We are confident that our friendship as vice-parents and vice-daughter and husband will hold forever.

**YY:** Everybody will agree that these are wonderful experiences, indeed. Could you sum up the scientific and the beyond-scientific results of our cooperation in one or two sentences?

**JM:** The resume is: Our Chinese-German cooperation has made valuable contributions to our science, and it has been a rich experience of life, not only for the principal investigators but also for the partners and students. In brief: one plus one yielded much more than two.

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