NEWSLETTER
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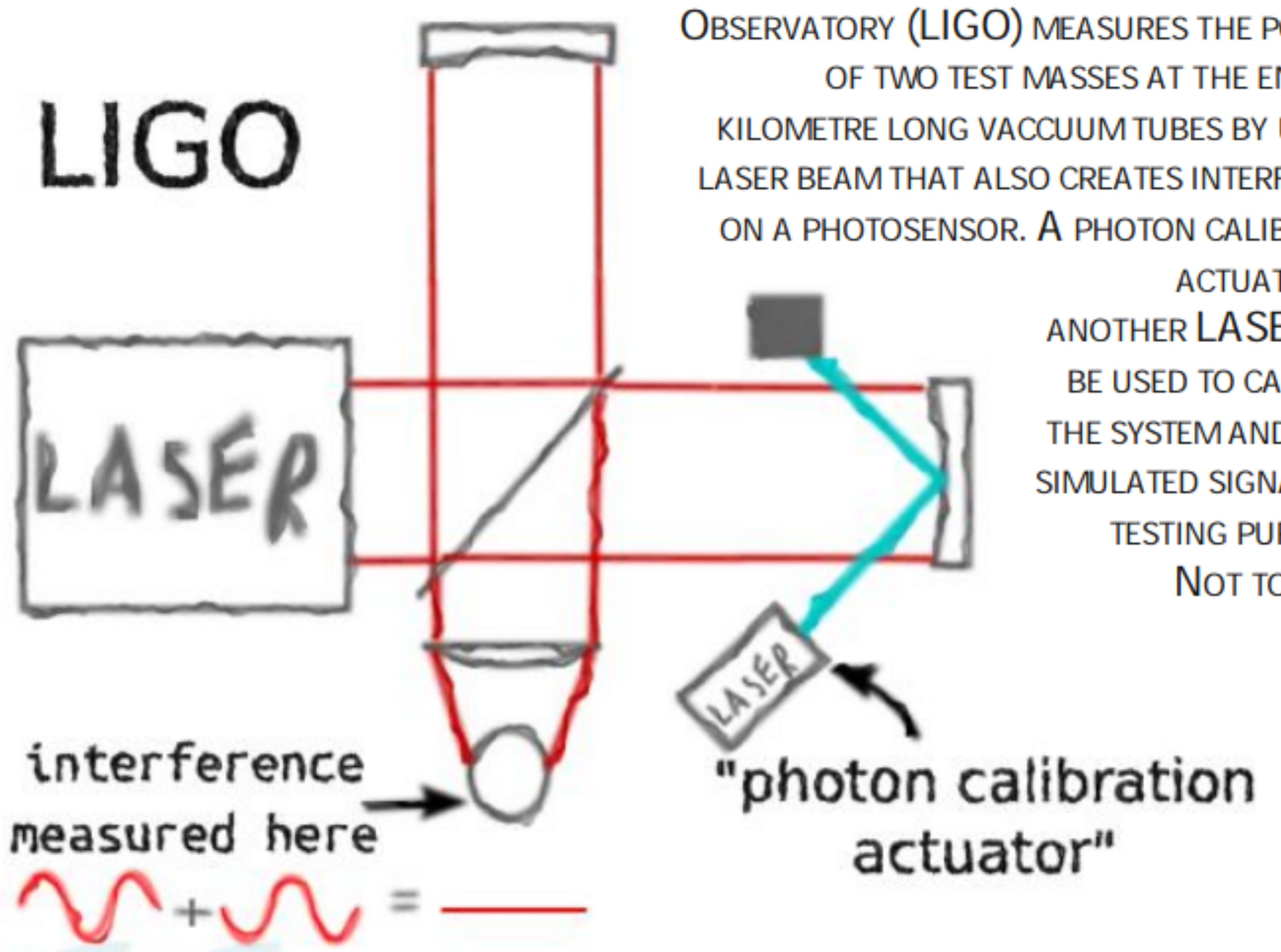
PHOQUS

Radiation pressure strikes again!

In a previous newsletter, I wrote about the connections between solar sails and optical tweezers. It might seem strange that two machines so vastly different in scale would rely on the same physics. Optical tweezers manipulate objects on the order of a micrometre or so, while a solar sail producing roughly 8 Newtons of thrust this close to the sun would be about a square kilometre in area. Nonetheless, physics apply everywhere in the universe and the rules don't change (except perhaps with a black hole's event horizon, but that's a topic for another day).



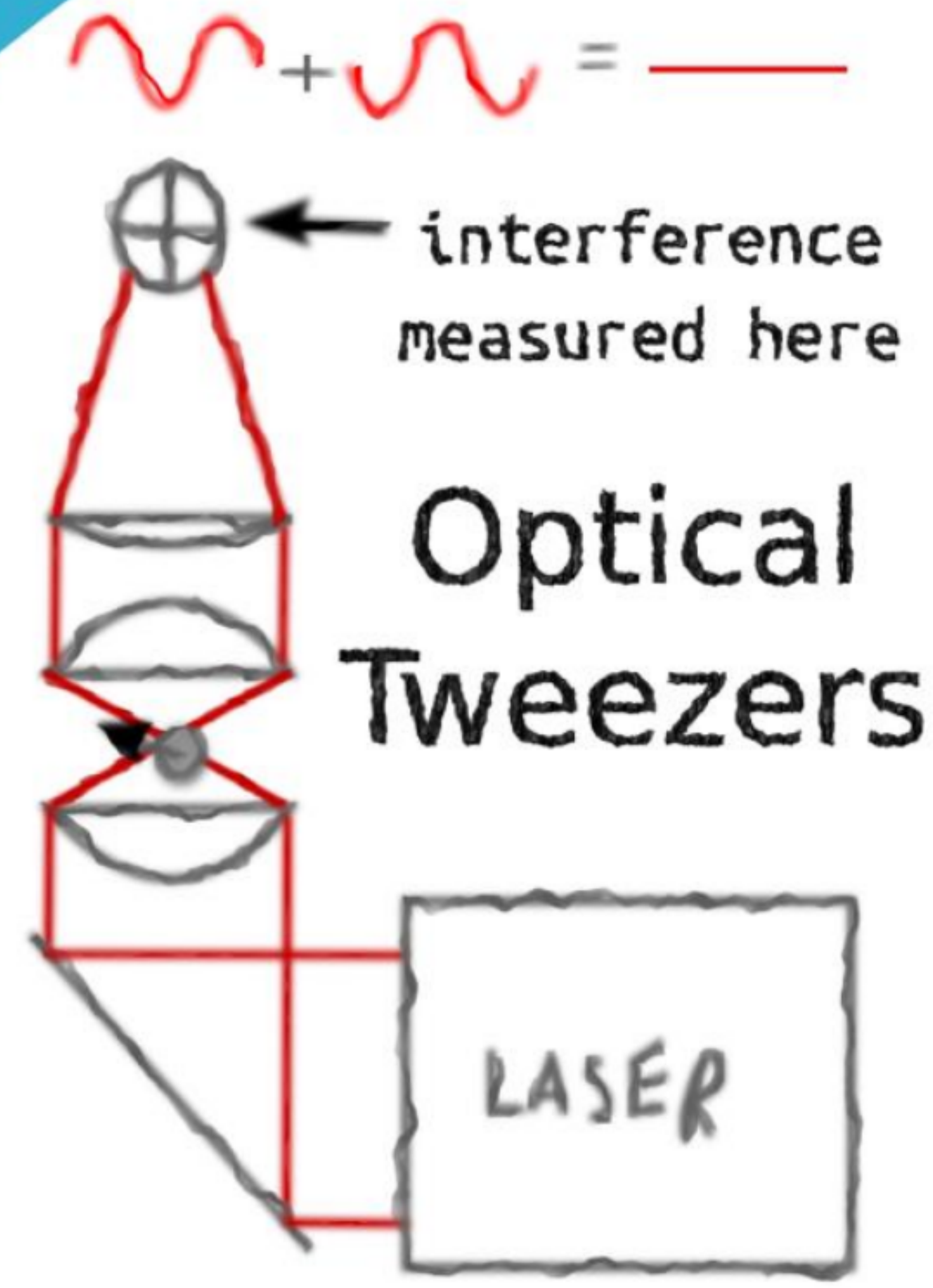
THE LASER INTERFEROMETRY GRAVITATIONAL OBSERVATORY (LIGO) MEASURES THE POSITION OF TWO TEST MASSES AT THE END OF 4 KILOMETRE LONG VACCUUM TUBES BY USING A LASER BEAM THAT ALSO CREATES INTERFERENCE ON A PHOTOSENSOR. A PHOTON CALIBRATION ACTUATOR (I.E. ANOTHER LASER) CAN BE USED TO CALIBRATE THE SYSTEM AND INJECT SIMULATED SIGNALS FOR TESTING PURPOSES. NOT TO SCALE.

> Optical tweezers don't need to be so sensitive as to detect a fluttering in spacetime, but calibration and engineering a signal processing workflow is just as important for biophysics experiments with optical tweezers as for their larger cousins, the gravitational wave detectors

As PHOQUS fellow no. 6, I build tools that use radiation pressure to study the mechanics of biological nanomachines. Investigating such small forces used by such small machines means vibrations are an important concern. A door closing in the office next door, an air-conditioning system, or a loud noise in the room all could potentially contaminate my signal. Therefore the microscope is built on top of an air-cushioned table occupying the better part of the lab, to separate the instrument from vibrations felt by the building. These measures pale, however, in comparison to the vibration isolation efforts of a much larger instrument measuring much smaller phenomena.

The Advanced Laser Interferometry Gravitational Observatories (aLIGO) in Hanover, Washington and Livingston, Louisiana, both in the USA made international headlines last year upon their announcement of a black hole binary merger observed in vibrations in spacetime. The ruler used to measure the ripples in spacetime, aka gravity waves, is of course light. Each instrument is a massive interferometer with each optical arm spanning 4 kilometres. Minute changes in path length show up as light or dark as the light waves are combined in (light) or out (dark) of sync. A number of clever active and passive vibration-damping systems, culminating in two millimetre-thin glass threads, decrease the influence of environmental noise by about 20 orders of magnitude. Putting that in perspective, the difference in height between a person and a virus is about 8 orders of magnitude. At the right frequencies, the aLIGO detectors can discern (over the 4km length of the optical cavity) a difference of about 1 attometer. But how can one calibrate such a machine?

Enter our good friend radiation pressure. aLIGO is so sensitive that it can detect the minute movements of



OPTICAL TWEEZERS MEASURE THE POSITION OF A TRAPPED (OR "TWEEZED") OBJECT WITH A LASER THAT CREATES AN INTERFERENCE PATTERN ON A PHOTO-SENSITIVE DETECTOR. NOT TO SCALE.

the test masses due to radiation pressure (the effect that I use to manipulate microscopic particles). To test the instrument and its' ability to observe distance changes of less than the size of a protein, an offset laser (different than the main laser that splits into two interferometer beams) propels photons that bounce off the test mass mirror. Photons have a minuscule amount of inertial mass, and when they change direction the resulting change in momentum has to be matched at the mirror, resulting in a tiny force experienced by the test mass. The large mirrors on the end of either cavity at each LIGO instrument tip the scales at 20 kg (that's 44 lbs) apiece, about as much as a small child or a large pile of kittens. Your intuition is correct if you expect that an object that massive will not move much in response to diverting a flow of light.

These so-called "photon-calibration actuators" are used by the LIGO team to probe the response of the LIGO interferometers and feedback control loops [4]. The various stabilization elements and their control software are designed to keep the system quiet enough to detect gravitational waves, and any real signals that LIGO does detect will be modified by the resulting transfer function. Therefore it's important to understand the transfer function contribution from each subsystem, to learn how the instrument will affect the gravitational wave signals that it measures.

These photon actuators can even be used as one of many ways to inject a simulated signal for testing purposes [1]. Interestingly enough, the scientists and engineers analysing the data don't generally know whether that data contains an injected signal. These simulated signals are therefore "blind injections" [2] and it's one way that scientists use to keep themselves honest- by not knowing what's going on. The most famous blind injection signal from LIGO was what became known as the "Big Dog" event during science run S6 (apparently originating from the constellation Canis major) [3]. This event made it all the way through peer review before the data were revealed to contain a hardware-based blind injection, serving as a litmus test for detecting and vetting gravitational wave signals.

Several of the early stage researchers working on PHOQUS projects are building tools to take advantage of radiation pressure to probe the inner workings of life. Optical tweezers don't need to be so sensitive as to detect a fluttering in spacetime, but calibration and engineering a signal processing workflow is just as important for biophysics experiments with optical tweezers as for their larger cousins, the gravitational wave detectors. As such many of the tools of time-frequency analysis used for matching LIGO data with theoretical sources of gravitational waves are very similar. For example, I've recently used data

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processing tutorials from the LIGO Open Science Center as a framework to develop wavelet analysis for optical tweezers experiments. Much like a feedback control loop stabilizing a gravitational wave detector, or stabilizing the force experienced by a protein under study with optical tweezers, the feedback loop from theory to experiment and back again is constantly evolving, richly cross-pollinated across disciplines as diverse as general relativity and single-molecule biophysics.

ARTICLE BY Q. TYRELL DAVIS (PHOQUS FELLOW NO. 6)

Further Readings:

1. Karki, S. et al. The Advanced LIGO Photon Calibrators. LIGO Doc. P1500249 (2016).
2. LIGO Scientific Collaboration. Blind Injection Stress-Tests LIGO and VIRGO's Search for Gravitational Waves.
3. LIGO Scientific Collaboration. Data for GW100916.
4. Goetz, E., et al. Precise calibration of LIGO test mass actuators using photon radiation pressure. Class. Quantum Grav 26.245011 (2009): 245011.

PHOQUS Fellow wins Poster Award at MIP2016

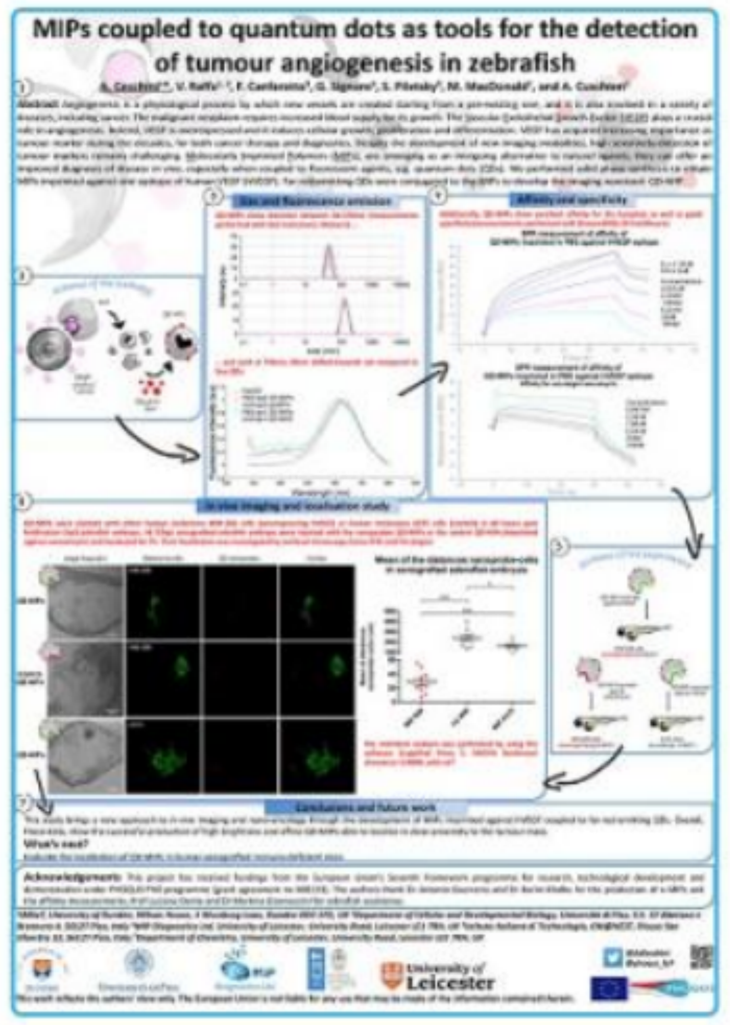
Molecular imprinting is a relatively new technology, which was developed about 40 years ago by Günter Wulff. During the years, the production of molecularly imprinted polymers (MIPs), also called "plastic antibodies", has evolved and spread all over the world. Thanks to their properties, MIPs have acquired increasing importance in several fields of scientific research, especially in cancer imaging and therapy.

Every two years the MIP meeting gathers the very experts of molecular imprinting from any labs. The 2016 meeting took place from 26-30th June in Lund, Sweden. The conference started with a talk by Prof Güther Wulff, the father of MIPs. During the meeting, Alessandra Cecchini (PHOQUS fellow no. 4) had the chance to have a chat with Prof Günter Wulff, Prof Karsten Haupt, Prof Sergey Piletsky, and Prof Claudio Baggiani and his team, and attended several very interesting talks, including one by Prof Kenneth Shea, the pioneer of protein molecular imprinting.

FROM LEFT: PROF GÜNTER WULFF (HEINRICH HEINE UNIVERSITY, GERMANY), MS ALESSANDRA CECCHINI (ESR4, UNIVERSITY OF DUNDEE, UK), PROF SERGEY PILETSKY (UNIVERSITY OF LEICESTER, UK).

The poster session was particularly stimulating; Alessandra presented her work to the most outstanding experts of MIPs who, like Prof Shea, invited other researchers to have a look at her work. The overall experience was intense, extremely helpful, a remarkable opportunity for being updated about the main progress in MIP applications and beneficial for networking. Additionally, Alessandra met many researchers who complimented her and found her results obtained so far interesting and complete, and last but not least she won the poster award!

ARTICLE BY ALESSANDRA CECCHINI (PHOQUS FELLOW NO. 4)



Poster: MIPs coupled to quantum dots as tools for the detection of tumour angiogenesis in zebrafish by A. Cecchini, V. Raffa, F. Canfarotta, G. Signore, S. Piletsky, M. MacDonald and Alfred Cuschieri.

Biophotonic approaches: From molecules to living systems Conference

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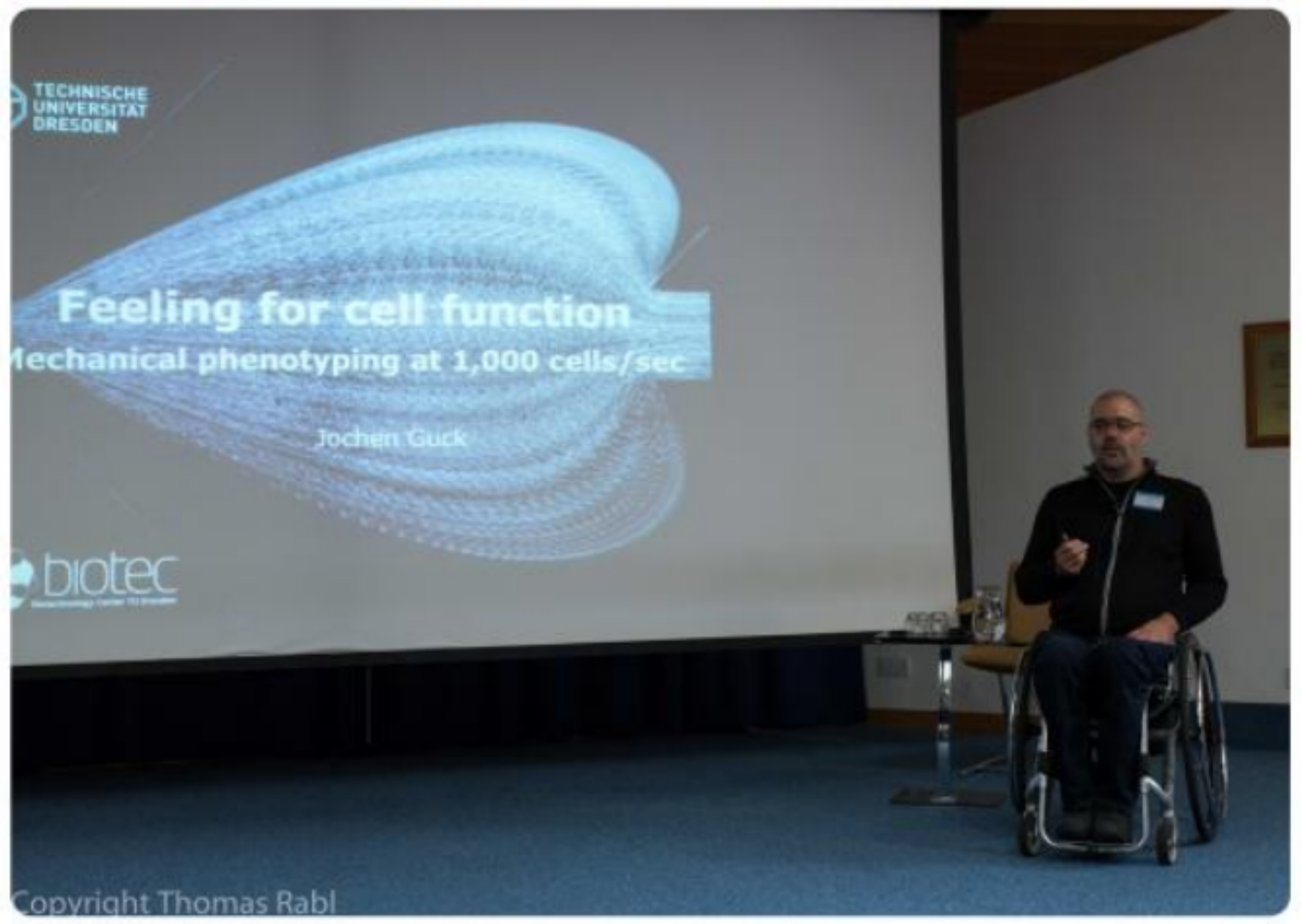

... Following a brief welcome from Prof. Kees Weijer, co-ordinator of the PHOQUS programme, the event started with a talk on Intravital imaging of drug target engagement from Erik Sahai of the Francis Crick Institute. Talks on the first day covered a range of topics from novel imaging techniques in vivo to talks on fundamental beam shaping and adaptive optics techniques. Among many fascinating talks, two highlights were the talks on Wave front shaping techniques from Monika Ritsch-Marte of the University of Innsbruck and the talk on in-vivo deep imaging from John Girkin of Durham University. The first day closed with a conference dinner attended by all of the invited speakers and the PHOQUS fellows. The dinner gave the fellows an opportunity to network with top notch scientists from all over the

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