CURRICULUM VITAE

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QUALIFICATIONS

1970-75 School of Telecommunications, Lodz (Poland). Diploma in Electronics.
1981 Lodz University of Technology (Poland). Master's degree (mgr inz) in Applied Physics.
1988 Hatfield Polytechnic. PhD in physics: *Investigations of Microbial Physiology and Cell Structure Using Laser Diffractometry.*

EMPLOYMENT

1982-88 Research Assistant – Physics Department, Hatfield Polytechnic.
1988-98 Research Fellow - Hatfield Polytechnic, then University of Hertfordshire.
1998-06 Senior Research Fellow - Science and Technology Research Institute, UoH, on open-ended (rolling) contract. Leader of Light Scattering Group.
2006-13 Reader in Optics - School of Physics Astronomy and Mathematics, and Centre for Atmospheric and Instrumentation Research, UoH. Leader of Light Scattering and Radiative Processes Group.
2013-19 Professor of Optics, Centre for Atmospheric and Instrumentation Research, now Centre for Atmospheric and Climate Processes (CACP) research, UoH.
2020- Contract scientist at British Antarctic Survey, visiting professor at Manchester University.

PROFESSIONAL INTERESTS AND EXPERTISE

My areas of interest are light scattering, characterization of aerosols, scattering properties of cirrus clouds, optical techniques for *in situ* and remote cloud sensing, optical instrument development, particle trapping and micromanipulation techniques. Although my work centres on light scattering - most recently atmospheric - I have broad interests and see myself as an interdisciplinary "problem solver" rather than a specialist in any narrow area. With background in optics and electronics, I have concentrated on the development of instruments and experimental techniques, but combine it with experimental and field work, computational modelling and fundamental theory.

MAIN SCIENTIFIC ACHIEVEMENTS

For brevity only the names of main co-workers are listed. See Recent Activities for more detail.

1987 During my PhD study, I showed that dehydration was responsible for the heat resistance of bacterial spores. This was achieved by measuring cell water content using laser light scattering. No other direct measurements of the water content of single-celled organisms were available then.[1-4]

1989 I developed the world's first optical trap based on a diode laser, which I later turned into the first stand-alone "laser tweezers" microscope. The instruments were designed for non-contact manipulation of single cells for biological and medical applications. Several patents [5-7] were granted on the basis of this work.[8-14]

1995 I developed a unique laser diffractometer for measuring the properties of single trapped microparticles, including living cells. The instrument is still in use, although the trapping method has changed from an optical to electrodynamic one. This instrument made possible the highly successful *Ice Scattering Experiments* project.[12,15-17]

1996 Together with Zhenni Wang I developed one of the first neural network techniques for deriving particle parameters from light scattering data. The technique is useful for rapid measurement of the size and other properties of small particles.[18-21]

1997 Using a novel measurement method, I showed that magnetic anisotropy accounted for the alignment of asbestos fibres in magnetic fields. This led to a patent [22] for a method of detecting airborne asbestos while at the same time discriminating against harmless materials. No other selective method for real-time detection of airborne asbestos exists.[23-30] It has been the basis of a €1.5M EU-funded project led by UoH.[30]

1999 Together with Ian Ludlow I developed a generalized description of non-paraxial electromagnetic beams.[11,31]

2000 I developed the first realistic analogues for atmospheric ice crystals (see Recent Activities).[16,17,32-40]

2001 Together with Evelyn Hesse I developed and verified experimentally a theory describing rotational dynamics of particles in electrodynamic levitation traps. This theory, and associated techniques, became the basis for further activities at UoH, including the *Ice Scattering Experiments* project.[41,42]

2001 Together with Evelyn Hesse I developed and tested a new electromagnetic scattering theory.[43-55]

2002 I produced the first optically-correct lab demonstration of the atmospheric halo.[56]

2003 I measured for the first time the scattering asymmetry parameter of a single microparticle. This parameter is fundamental to describing atmospheric clouds and aerosols in climate models.[16,33,34,52,57,58]

2004 Together with James Hough I developed a polarimeter for the remote sensing of cirrus and atmospheric aerosols (see Recent Activities).

2005 I developed a technique for the measurement of light scattering from single microparticles in randomized orientation and determined their scattering phase functions. In related experiments I also measured 2-D scattering patterns from ice-like crystals, again for the first time. Both measurements are valuable for testing theoretical scattering models, as input to climate prediction modelling, and for calibrating atmospheric instruments.[33,36,37,44,58,59]

2007 I provided the interpretation of polarimetric observations showing, for the first time, the presence of aligned aerosol particles in the atmosphere.[60-65]

2009 I led the development of the first “disposable” aerosol radiosonde, used in 2009 for measurements of airborne desert dust and 2010 for detecting the Eyjafjallajökull volcanic ash plume.[66-79]

2010 I developed a non-contact technique for quantifying particle roughness and used it to demonstrate that the majority of ice particles in mid-latitude clouds did not have smooth, regular shapes.[76,80-89] The work is described in the most frequently cited paper from the UK airborne research community published since 2014.[80]

2012 I developed a new technique for sizing small particles using laser speckle.[90,91]

2015 I provided interpretation of new measurements of tropical tropopause cirrus showing for the first time the presence of rounded ice particles.[92,93]

2017 I documented a new atmospheric optical phenomenon and proposed its application to semi-remote sensing of low-level clouds in the polar regions.[94] This provided evidence for a cloud process postulated earlier, radiatively-induced precipitation,[95] and led to a new study with NASA and NCAR and a computational model of ice crystal alignment.[96]

2018 Together with teams at IfT and AIDA I established through lab experiments the connection between ice growth rate and cycling and crystal roughness.[97-99]

2019 Together with a team at KIT I developed a modular sonde system, now available as dropsondes on the HALO and soon FAAM research aircraft, and as balloon upsondes.[100-106]

2020 I led the development of a dedicated multicopter for atmospheric measurement and a “hardened” version of UCASS (RCASS).[107]

R&D PROJECTS AND MAJOR GRANTS - SUMMARY

Leading researcher unless indicated otherwise (not a named Investigator prior to 1999 due to research council eligibility criteria for contract research staff). The source and amount of external funding are given in brackets.

1988-00 Optical trapping of microparticles and cells. See Main Achievements above.
1989-91 Laser Scattering Particle Sorter (SERC £71k). Continued as:
1993-96 Advanced Laser Diffractometer (EPSRC £82k). See Main Achievements above.
1993-97 Applications of numerical optimisation to inverse scattering problems.[108-114]
1995-01 Applications of neural networks in light scattering. See Main Achievements above.
1995-05 Theory of electromagnetic beams, with application to optical traps. See below.

1995-05 Development of a technique for detecting airborne asbestos fibres (DTI, EPSRC, industry approx. £134k – co-investigator, lead after 2000). See Main Achievements.
1999- Ice Scattering Experiments (NERC, EPSRC £330k). See below.
2000-05 Remote sensing of cloud composition using imaging polarimetery. See below.
2000- Theory of scattering from atmospheric ice crystals. See below.
2002-04 *Cryptosporidium* detection in drinking water (EPSRC, industry £150k – Co-I).
2003-06 Single Particle Raman Spectrometer (NERC, EPSRC, DSTL, British Council £173k). A novel instrument for physicochemical analysis of single aerosol particles, intended for measurements on aerosols sampled from the atmosphere, as well as for laboratory studies. It combines elastic and Raman scattering for small by taking advantage of electrodynamic particle capture and levitation. This allows the analysis of the size, shape and chemical composition of aerosol particles.[115,116]
2005-08 Spectropolarimeter for remote sensing of aerosols and clouds (NERC £70k).
2004- Characterization, calibration and application of *in situ* cloud probes (NERC, EU ACCENT, EUROCHAMP-2, Helmholtz Gemeinschaft ~£570k – Co-I or PI). See below.
2006-11 Aerosol Interactions in Mixed Phase Clouds (NERC APPRAISE £233k+£61k via U.Reading). See 3 below.
2009-10 Dust Radiation, Electrification and Alignment in the Middle East (NERC DREAME £88k). See 4 below.
2010-13 Airborne asbestos fibre detection (EU £535k – Co-I). See Main Scientific Achievements.
2012-15 Aerosol-Cloud Interactions (NERC ACID-PRUF £272k). See 3 below.
2012-16 Co-ordinated Airborne Studies in the Tropics (CAST, NERC £284k – Co-I). See 9 below.
2013-14 Universal cloud and aerosol sonde system (UCASS, NERC £99k). See 8 below.
2013-16 Cirrus Coupled Cloud−Radiation Experiment (CIRCCREX, NERC via IC £44k).
2015-19 Cloud and aerosol dropsondes for FAAM aircraft (NERC £381k). See 8 below.
2018-23 Does dust TriboElectrification affect ClimaTe? (D-TECT, NOA €40k). See 4 below.
2020-24 Improving Cirrus Estimates of Radiative Forcing (ICE-RF, NERC £k616 – Co-I). Shared between UoM and UoH.

The total external research funding I have been instrumental in obtaining at UoH has been over £3M, excluding my contribution (together with Profs. Kaye and Hough) to winning over £2M of JIF and SRIF funding, PhD studentship income and several contracts for building cloud and aerosol characterization instruments that I secured.

RECENT ACTIVITIES

The main areas of activity that I am currently leading or have recently led at UoH, or play a major role in, are described below.

1. **Ice Scattering Experiments.** This is a fundamental laboratory and theoretical investigation into light-scattering properties of non-spherical particles, with special emphasis on cirrus ice. Characteristics of single microparticles are studied using electrodynamic levitation traps and novel ice analogues – particles that resemble ice – that I have developed. The analogues allow studying ice while removing the need to reproduce atmospheric conditions in the laboratory – a requirement that is difficult to meet. The analogues are also being used for the calibration of *in situ* cloud probes (see 2 below). The detailed knowledge gained in this way should allow more accurate modelling of atmospheric phenomena and climate, where atmospheric ice particles are acknowledged to contribute to some of the greatest uncertainties. The results have been used, among others, in the verification of the atmospheric radiation component of the Met Office's HadCM3 Global Circulation Model, used for climate prediction. The project was listed among top eight science achievements funded by NERC in 2002 (out of ≈400 grants), was featured in the *Planet Earth* quarterly and the NERC 2002 Annual Report, and was given a 15 minute slot on BBC Radio 4 *Material World* (22/5/2003). More details of this project can be found on the CACP website.[16,33-36,41,49,52,56,117-119] Parts of the project have continued in various form as other activities, e.g. 2, 3, 5-8 below.[98,99,120]
2. **Characterization, calibration and application of *in situ* cloud probes.** This major ongoing activity extends, and is complementary to, the development of the successful Small Ice Detector (SID) series of instruments (work led by Prof. Paul Kaye). To date, >12 versions of these instruments have been built, including three for the UK national atmospheric research

aircraft (FAAM), and further ones for a similar US facility (HIAPER), Colorado State Uni./NASA cloud chamber, the German national research aircraft HALO, the AIDA cloud chamber and the Institute for Tropospheric Research in Germany, UK Met Office, the University of Manchester cloud chamber, and the NASA high-altitude Global Hawk UAV. I have been leading the characterization, data analysis for, and scientific application of these probes. The ice analogues and the Ray Tracing with Diffraction on Facets (RTDF, see *EM Theory* below) have been used to investigate the performance of, and provide particle measurement and classification tools for, several atmospheric ice particle probes. These include in addition to the SID family the PHIPS instrument for HALO (currently the highest optical resolution *in situ* ice probe)[119,121] and the Cloud Particle Imager (CPI).[122,123,124] The characterization of other probes has been continuing since then, most recently CIP-15 and 2DS at UoM.[77,80,82,85-90,97,119,125-146]

3. **Cloud-aerosol interactions.** Starting with the NERC APPRAISE programme and continued as the *ACID-PRUF* consortium these NERC-funded activities provided advances in the understanding of the nature and lifecycle of aerosols in the atmosphere and key information on aerosol and cloud properties and their effects on climate. This information is intended for the development of climate models with the aim of improving the representation of aerosol and cloud processes, and reducing the uncertainty in climate change predictions. The main components of the programme at UoH were:
   - ***Improved representation and validation of the radiative properties and impacts of aerosols and clouds***. The UoH component, with £61k of funding from NERC, was concerned with the provision of light-scattering algorithms and parametrizations for use in the *Community Radiative Transfer Code*, which will form the UK basis for the modelling of the impact of aerosols on climate.[147]
   - ***Aerosol Interactions in Clouds***. This sub-project, funded by two NERC grants, involved consortia of UK universities (Manchester, Leeds, Oxford, Bristol and Reading in addition to UoH) and the Met Office. My contribution focused mainly on determining the properties of particles during ice nucleation and growth experiments in AIDA (arguably the world's best equipped cloud chamber located at KIT, Germany) and in the IRIS diffusion tube at IfT (Leipzig), and during aircraft campaigns. Notable outcomes from this project that I personally led were the finding that the majority of ice particles in mid-latitude clouds had rough surfaces,[76,80,81,83-87,148] a new technique for sizing small particles using laser speckle analysis,[90,91] and establishing the connection between ice growth rate and cycling and crystal roughness.[97,98,99]

   These projects formally ended in 2016 but led to others, including CIRCCREX and CAST.
4. **Atmospheric dust alignment.** This interdisciplinary project stems from a serendipitous observation of unexpected polarization of stellar radiation with Planetpol, an ultrasensitive astronomical polarimeter co-developed by Jim Hough together with CACP. I interpreted this polarization as originating from alignment of atmospheric mineral dust due to electric fields generated by a Saharan dust storm. No previous accounts exist of atmospheric aerosol alignment. The significance of this discovery is in the influence on remote sensing retrievals, and on the radiative balance of the atmosphere. In addition to modelling, field measurements were carried out in Kuwait, Saudi Arabia and on Cape Verde as part of the NERC DREAME project that I led.[60-64,149] One unexpected outcome was that unique balloon-borne aerosol sondes developed for DREAME proved invaluable for detecting airborne ash during the Eyjafjallajökull eruption (see 7 below). This project is ongoing. Among others, it has been the motivation for a major international collaboration led by the National Observatory of Athens (D-TECT, €2M).[150] The development offshoot of this project is described in 8 below.
5. **Aerosol-Cloud Interactions - Virtual Institute.** A "virtual institute" was established with funding from the Helmholtz Association (Helmholtz-Gemeinschaft). Entitled "*Role of aerosol particles as condensation and ice nuclei in tropospheric clouds*", it was led by Karlsruhe Institute of Technology (KIT), in collaboration with Forschungszentrum Jülich, Institute for Tropospheric Research (IfT), three German universities, ETH Zürich and Tel Aviv University. My contribution was similar to that in the *APPRAISE* project. This project has ended formally but several of the collaborations are continuing, most notably with IfT and KIT.[97-99]

6. **Electromagnetic Theory.** The applied light scattering and instrumentation work I carry out is underpinned by fundamental theory studies, including both direct and inverse scattering problems. My recent significant achievements are:
   - New scattering theory based on a unification of diffraction with geometric optics – RTDF. In one of its forms it has been applied to scattering from atmospheric ice crystals. From the fundamental point of view, it is significant as a new formulation of diffraction; from the practical point of view, the approximation is important in atmospheric scattering since it is computationally as efficient as existing geometric optics-based methods but substantially more accurate.[38,43-55,151]
   - Generalized description of non-paraxial electromagnetic beams. It is the first such model that is both exact and closed-form, and it includes the fundamental-mode Gaussian beam as a special case. This highly-cited work has been applied at UoH to optical trapping of microparticles and, elsewhere, to ultrashort pulse propagation.[9,11,152]
7. **Remote sensing of clouds and aerosols**. This interdisciplinary area linked to the dust work in 4 above concerns the development of instruments and techniques for measuring atmospheric properties from the ground using both polarized and unpolarized radiances, and needed for climate, weather and air quality study. As the leader of the Light Scattering and Radiative Processes research group, I developed links with the Centre for Astrophysics Research (CAR) at UoH to exploit synergies existing between these groups.[60-62,154,153] Results from validations using simultaneous polarimetry, radar and lidar observations have demonstrated the ability to determine particle shape and composition of mixed-phase clouds and the potential to retrieve aerosol properties. The project also takes advantage of the RTDF model to compute the radiative properties of cirrus. In an early stage a spectropolarimeter was developed jointly with CAR, where in addition to angular dependence of polarization spectral dependence is measured too. This was followed by the development of an ultra-sensitive extinction polarimeter, a transportable version of Planetpol.[60,61,154] Both will be used in the international campaign led by the National Observatory of Athens (D-TECT, see 4 above). Since 2010 I have been setting up the Bayfordbury Remote Sensing Observatory, equipped with photometers, radiometers, all-sky cameras and lidar – see https://www.herts.ac.uk/bayfordbury/bayfordbury-observatory/remote-sensing. A new technique I developed there provides information on the microphysical and radiative properties of cirrus by determining the so-called halo ratio.[155] Lastly, as an outcome from the cloud probe work in 2 above I developed a method for near-field remote sensing of boundary-layer ice clouds and “diamond dust”.[94]
8. **Cloud and Aerosol Radiosondes.** Evolved from the *Atmospheric Dust Alignment* project and initially funded by three NERC grants, it focused on the development and application of low-cost, non-recoverable sondes for characterising cloud and aerosol particles. During the DREAME project in 2009 I led the development of unique balloon-borne aerosol counters - the first "aerosol radiosondes". They measure the size distribution and concentration of aerosols such as airborne dust. The sondes turned out to be extremely valuable for detecting airborne ash during the Eyjafjallajökull eruption in 2010. These widely publicized measurements were used to verify the Met Office ash dispersion model and provided evidence for maintaining airspace closure. The Met Office commissioned a further 20 units for future emergencies, and some of them were used during the less-severe Grimsvotn event.[66-79,156] Improved balloon-borne and aircraft-deployed sondes have now been developed, and generated considerable interest in the scientific, weather prediction and aviation community.[100-106,156-157] I received requests for sondes from, among others: Met Office, U. Santiago, U. Athens, BAS, NASA, NOAA, ACTRIS, Cyprus Institute, FMI, Meteo France and NARL (India).
9. **Tropical Tropopause Layer (TTL) Cirrus.** Funded by the NERC CAST grant, this project in collaboration with NASA, NOAA, SPEC Inc. and several US and UK universities focuses on *in situ* measurement of the properties of upper troposphere and lower stratosphere cirrus using high-altitude aircraft. For this purpose a new instrument was developed in CACP for deployment on the NASA Global Hawk UAV. The first results obtained in 2015 provided more detailed data on TTL cirrus than previously available, which I interpreted to indicate rather unexpected composition.[92,93] This work capitalizes on the ability of the RTDF model to represent the scattering properties of ice crystals and on the ice analogues developed during

the *Ice Scattering Experiments*. Subsequently I was invited to participate in the NASA POSIDON mission in 2016, to which I contributed an instrument for the WB57 aircraft.[158] This ongoing work was given a NASA Group Achievement Award in 2017.

RECENT PHD SUPERVISION

Student	Project title	Funding	Role	Completion
R. Dorizzi	Computation of radiation forces in focused Gaussian beams	Self-funded	1st	2005
C. Morriss	Real-time detection of asbestos fibres	EPSRC CASE	1st	2006
A. Clarke	Computation of scattering from atmospheric ice crystals	EPSRC CASE	2nd	2006
J. Dalley	Capture and physicochemical analysis of atmospheric aerosols	EPSRC	2nd	2006
B. Bercot	Remote sensing of cloud composition using polarimetery	UoH	1st	2008
C. Stopford	Two-dimensional scattering from small ice crystals	NERC	1st	2010
D. McCall	Experiments on and computations of scattering properties …	NERC	2nd	2011
G. Ritter	Ice particle surface properties under cirrus cloud conditions ...	UoH	1st	2014
C. Collier	Experimental and computational investigation into light scattering...	NERC	2nd	2014
P. Dandini	Cirrus occurrence and properties determined from ground-based...	UoH	1st	2017
L. Taylor	Modelling and measurement of light scattering by airborne particles	NERC	2nd	2017
J. Thornton	Ice crystal roughness and its impact on radiative properties of clouds	UoH	1st	2017
M. Kezoudi	Mineral dust profiling with UCASS radiosondes	UoH	2nd	2020
J.Girdwood	Aerosol and cloud measurements using UAVs	UoH	2nd	2023

PUBLICATIONS (selected conference presentations shown only)

Key

Refereed journal publications
Patents
Book chapters

[1] **Ulanowski** Z. & I.K. Ludlow & W.M. Waites (1987) Water-content and size of spore components determined by laser diffractometry. *FEMS Microbiol. Lett.* 40, 229-232.
[2] **Ulanowski** Z. & I.K. Ludlow (1989) Water distribution, size and wall thickness in *Lycoperdon-pyriforme* spores. *Mycological Res.* 93, 28-32.
[3] **Ulanowski** Z & I.K. Ludlow (1993) The influence of the cortex on protoplast dehydration in bacterial-spores studied with light-scattering. *Current Microbiology* 26, 31-35.
[4] **Ulanowski** Z. & Ludlow I.K. (1988) Laser diffractometry measurements show that cortex contraction is involved in dehydrating spore protoplast. *10th Int. Spore Conf.*, Woods Hole.
[5] **Ulanowski** Z. *Optical microscopes*. Patent GB 2231681- granted 1990.
[6] **Ulanowski** Z. *Optical microscopes*. European Patent Application 486732A1 - awarded 1990 (not taken through to grant stage due to high costs).
[7] **Ulanowski** Z. *Optical microscopes*. US5225929 - granted 1993. These three patents describe a method for generating a strongly focused light beam, suitable for generating an optical trap using a microscope.
[8] **Ulanowski** Z. & I.R. Williams (1996) Optical tweezers. *Phys. Ed.* 31, 179-182.

[9] **Ulanowski** Z. & I.K. Ludlow (2000) Compact optical trapping microscope using a diode laser. *Meas. Sci. Technol.* 11, 1778–1785. Selected as Featured Article by the editor.
[10] **Ulanowski** Z. (2001) Optical tweezers - principles and applications. *Proc. Roy. Microsc. Soc.* 36, 7-14. Invited review.
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[13] **Ulanowski** Z. (1996) Applications of optical trapping. SIA Conf., London. Invited.
[14] **Ulanowski** Z. (1996) Applications of optical trapping. Institute of Food Research, Norwich. Invited.
[15] **Ulanowski** Z., R.S. Greenaway, P.H. Kaye & I.K. Ludlow (2002) Laser diffractometer for single particle scattering measurements. *Meas. Sci. Technol.* 13, 292-296.
[16] **Ulanowski** Z., E. Hesse, P.H. Kaye, A.J. Baran & R. Chandrasekhar (2003) Scattering of light from atmospheric ice analogues. *J. Quantit. Spectr. Rad. Transf.* 79-80C, 1091-1102.
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[18] **Ulanowski** Z., Z. Wang, P.H. Kaye & I.K. Ludlow (1998) Application of neural networks to the inverse light scattering problem for spheres. *Appl. Opt.* 37, 4027-33.
[19] Wang Z., Z. **Ulanowski**, & P.H. Kaye (1999) On solving the inverse scattering problem with RBF neural networks. *Neural Computing Appl. J.* 8, 177-186.
[20] Hirst E., Z. **Ulanowski**, P.H. Kaye & Z. Wang-Thomas (1998) Spatial light scattering as a means of discriminating hazardous respirable fibres. *5th Int. Congr. Optical Particle Sizing*, Minneapolis, pp.233-236.
[21] **Ulanowski** Z., J. Meng & P.H. Kaye (2000) Optimization of light scattering particle sizing using neural networks. *Proc. Appl. Optics & Optoel. Conf.*, IoP, Loughborough, pp.31-32.
[22] **Ulanowski** Z. & P.H. Kaye. *Improved method and apparatus for detection of asbestos fibres*. Patent GB 2333835 - granted 1999.
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[25] **Ulanowski** Z., Kaye P.H. & Hirst E. (1998) Detection of airborne asbestos fibres using magnetic alignment and light scattering. *Int. Conf. on Lasers & Electro-Optics/Europe,* IEEE, Glasgow.
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[27] **Ulanowski** Z. (1999) Enhanced asbestos fibre detection using magnetic alignment. *Particles in the Environment*, Royal Society of Chemistry, London, 31st March.
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[29] Morriss C.D. & **Ulanowski**, Z. (2003) Alignment of fibrous particles in an aerosol delivery system designed for asbestos detection. *Eur. Aerosol Conf.*, Madrid.
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[37] **Ulanowski** Z., Hesse E., Baran A.J., Kaye P.H. & Tongue I. (2003) Atmospheric ice crystal analogues for light scattering measurements. *EGS/AGU/EUG Joint Assembly*, Nice. In: *Geophys. Res. Abstr.* 5, p.12728.
[38] Hesse E. & **Ulanowski** Z. (2003) Scattering from long hexagonal prisms - experimental results and computations using ray tracing combined with diffraction on facets. *Ibidem*, p.12892
[39] Kaye P.H., **Ulanowski** Z., Hesse E. & Baran A.J. (2003) New atmospheric ice crystal analogues. *Royal Meteorol. Soc. Conf. 2003,* Norwich.
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