

# Samuel Jacobi Grauer

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## CONTACT INFORMATION

1080 Peachtree St NE  
Unit 1316  
Atlanta, GA 30309 United States

*Phone* +1 (470) 439-7599  
*Email* [sgrauer3@gatech.edu](mailto:sgrauer3@gatech.edu)  
*Web* [samgrauer.ca](http://samgrauer.ca)

## RESEARCH INTERESTS

Bayesian analysis of challenging inverse problems  
3D imaging: background-oriented schlieren (BOS) tomography, chemiluminescence tomography  
Spectroscopy: 2D hyperspectral imaging, velocimetry/thermometry of hypersonic flows  
Nanoparticle diagnostics: adapting laser-induced incandescence to probe fundamental properties

## EDUCATION

**University of Waterloo**, Waterloo, ON Canada

Ph.D., Mechanical and Mechatronics Engineering, 2018-09-10

- Thesis: [Bayesian methods for gas-phase tomography](#)
- Advisor: Kyle Daun

**University of Manitoba**, Winnipeg, MB Canada

B.Sc., Mechanical Engineering, 2014-06-03

- Thesis: Development of correlations for laminar film condensation in a non-condensing gas
- Advisor: Scott Ormiston

## RESEARCH EXPERIENCE

**Georgia Institute of Technology**, Atlanta, GA United States

*Postdoctoral Fellow*

**September 2018–Present**

Developing novel optical diagnostics to measure 3D velocity, temperature, and composition fields in complex flames, high-speed flows, and disparate-viscosity mixing processes. Focused on limited-data problems and statistical analysis.

**NSERC FlareNet Strategic Network**, Ottawa, ON Canada

*Doctoral Researcher*

**January 2017–September 2018**

Developed models for hyperspectral imaging of gas-phase flare emissions to conduct stand-off measurements of combustion efficiency.

**University of Duisburg-Essen**, Duisburg, Germany

*Visiting Scholar*

**September 2017–December 2017**

Established BOS tomography capabilities at UDE with Prof. Mohri and published the first paper on BOS-based combustion tomography in the literature.

**University of Waterloo**, Waterloo, ON Canada

*Undergraduate Research Assistant*

**May 2013–August 2013**

Investigated the chemical kinetics of an industrial Al-Si coating for steel blanks.

**Atomic Energy of Canada Ltd.**, Chalk River, ON Canada

*Undergraduate Research Assistant*

**May 2013–August 2013**

Characterized heat flux sensor performance in a high-temperature, high-humidity environment.

## AWARDS & SCHOLARSHIPS

Postdoctoral Fellowship (PDF)

NSERC, 2018-10  
CAD 90,000

Postgraduate Scholarships-Doctoral Program (PGS D3)

NSERC, 2016-05  
CAD 63,000

President's Graduate Scholarship <i>Awarded in conjunction with federal Tri-Agency funding</i>	University of Waterloo, 2016-05 CAD 30,000
Domestic Doctoral Engineering Scholarship	University of Waterloo, 2015-01 CAD 11,333
University of Waterloo Graduate Award ( $\times 10$ ) <i>Awarded for high performance in a previous term (e.g., for a publication)</i>	University of Waterloo CAD 7,250
Research Explorer Ruhr (RER) Programme <i>Awarded to conduct flame imaging experiments at the University of Duisburg-Essen</i>	University Alliance Ruhr, 2019-06 EUR 2,250
David Johnston International Experience Award <i>Awarded in support of a three-month research campaign</i>	University of Waterloo, 2017-09 CAD 2,500
Outstanding Teaching Assistant Award	Dept. MME, University of Waterloo, 2017-01

TEACHING  
EXPERIENCE

TA	Ordinary Differential Equations (ME 203)	University of Waterloo	Spring 2017
TA	Ordinary Differential Equations (MTE 202)	University of Waterloo	Winter 2017
TA	Heat Transfer II (ME 456)	University of Waterloo	Fall 2016
TA	Heat Transfer I (ME 353)	University of Waterloo	Fall 2016
TA	Thermodynamics and Heat Transfer (ECE 309)	University of Waterloo	Spring 2016
TA	Technology, Society, and the Future (CIVL 4460)	University of Manitoba	Winter 2014

JOURNAL  
PUBLICATIONS

- S1. Miguel, R.B., J. Emmert, **S.J. Grauer**, J. Thornock, and K.J. Daun, "Filter selection method for quantitative optical gas imaging of multicomponent mixtures," *J. Quant. Spectrosc. Radiat. Transfer* (Submitted).
- J13. **Grauer, S.J.**, and A.M. Steinberg, "Fast and robust volumetric refractive index measurement by unified background-oriented schlieren tomography," *Exp. Fluids* **61**(3), 80 (2020) doi: [10.1007/s00348-020-2912-1](https://doi.org/10.1007/s00348-020-2912-1)
- J12. Emmert, J., **S.J. Grauer**, S. Wagner, and K.J. Daun, "Efficient Bayesian inference of absorbance spectra from transmitted intensity spectra," *Opt. Express* **27**(19), 26893–26909 (2019) doi: [10.1364/OE.27.026893](https://doi.org/10.1364/OE.27.026893)
- J11. **Grauer, S.J.**, J. Emmert, S.T. Sanders, S. Wagner, and K.J. Daun, "Multiparameter gas sensing with linear hyperspectral absorption tomography," *Meas. Sci. Technol.* **30**(10), 105401 (2019) doi: [10.1088/1361-6501/ab274b](https://doi.org/10.1088/1361-6501/ab274b)
- J10. **Grauer, S.J.**, A. Unterberger, A. Rittler, K.J. Daun, A.M. Kempf, and K. Mohri, "Instantaneous 3D flame imaging by background-oriented schlieren tomography," *Combust. Flame* **196**, 284–299 (2018) doi: [10.1016/j.combustflame.2018.06.022](https://doi.org/10.1016/j.combustflame.2018.06.022)
- J9. Sipkens, T.A., P.J. Hadwin, **S.J. Grauer**, and K.J. Daun, "Predicting the heat of vaporization of iron at high temperatures using time-resolved laser-induced incandescence and Bayesian model selection," *J. Appl. Phys.* **123**(9), 095103 (2018) doi: [10.1063/1.5016341](https://doi.org/10.1063/1.5016341)
- J8. **Grauer, S.J.**, B.C. Conrad, R.B. Miguel, and K.J. Daun, "Gaussian model for emission rate measurement of a heated plume using hyperspectral data," *J. Quantit. Spectrosc. Radiat. Transfer* **206**, 125–134 (2018) doi: [10.1016/j.jqsrt.2017.11.005](https://doi.org/10.1016/j.jqsrt.2017.11.005)
- J7. Sipkens, T.A., P.J. Hadwin, **S.J. Grauer**, and K.J. Daun, "General error model for analysis of laser-induced incandescence signals," *Appl. Opt.* **56**(30), 8436–8445 (2017) doi: [10.1364/AO.56.008436](https://doi.org/10.1364/AO.56.008436)
- J6. **Grauer, S.J.**, P.J. Hadwin, T.A. Sipkens, K.J. Daun, "Measurement-based meshing, basis selection, and prior assignment in chemical species tomography," *Opt. Express* **25**(21), 25135–25148 (2017) doi: [10.1364/OE.25.025135](https://doi.org/10.1364/OE.25.025135)

- J5. **Grauer, S.J.**, R.W. Tsang, and K.J. Daun, “Broadband chemical species tomography: Measurement theory and a proof-of-concept emission detection experiment,” *J. Quant. Spectrosc. Radiat. Transfer* **198**, 145–154 (2017) doi: [10.1016/j.jqsrt.2017.04.030](https://doi.org/10.1016/j.jqsrt.2017.04.030)
- J4. **Grauer, S.J.**, P.J. Hadwin, and K.J. Daun, “Improving chemical species tomography of turbulent flows using covariance estimation,” *Appl. Opt.* **56**(13), 3900–3912 (2017) doi: [10.1364/AO.56.003900](https://doi.org/10.1364/AO.56.003900)
- J3. **Grauer, S.J.**, P.J. Hadwin, and K.J. Daun, “Bayesian approach to the design of chemical species tomography experiments,” *Appl. Opt.* **55**(21), 5772–5782 (2016) doi: [10.1364/AO.55.005772](https://doi.org/10.1364/AO.55.005772)
- J2. Daun, K.J., **S.J. Grauer**, and P.J. Hadwin, “Chemical species tomography of turbulent flows: Discrete ill-posed and rank deficient problems and the use of prior information,” *J. Quant. Spectrosc. Radiat. Transfer* **172**, 58–74 (2016) doi: [10.1016/j.jqsrt.2015.09.011](https://doi.org/10.1016/j.jqsrt.2015.09.011)
- J1. **Grauer, S.J.**, E.J.F.R. Caron, N.L. Chester, M.A. Wells, and K.J. Daun, “Investigation of melting in the Al-Si coating of a boron steel sheet by differential scanning calorimetry,” *J. Mater. Process. Technol.* **216**, 89–94 (2015) doi: [10.1016/j.jmatprotec.2014.09.001](https://doi.org/10.1016/j.jmatprotec.2014.09.001)

REFEREED  
CONFERENCE  
CONTRIBUTIONS

**Papers**

- C21. **Grauer, S.J.**, J. Emmert, A.M. Steinberg, S. Wagner, and K.J. Daun, “Hyperspectral absorption tomography with a lineshape prior,” at *11th US National Combustion Meeting*, Pasadena, CA, Mar. 24–27, 2019 (10 pp.).
- C20. **Grauer, S.J.**, A. Unterberger, K.J. Daun, and K. Mohri, “Demonstration of instantaneous 3D flame reconstruction by background-oriented schlieren tomography,” at *Combustion Institute/Canadian Section Spring Technical Meeting*, Toronto, Canada, May 14–17, 2018 (6 pp.).
- C19. Miguel, R.B., **S.J. Grauer**, T.A. Sipkens, and K.J. Daun, “Optical measurement of hydrocarbon gas mixtures using MWIR broadband cameras,” at *Combustion Institute/Canadian Section Spring Technical Meeting*, Toronto, Canada, May 14–17, 2018 (6 pp.).
- C18. Sipkens, T.A., P.J. Hadwin, **S.J. Grauer**, and K.J. Daun, “Using Bayesian model selection and time-resolved laser-induced incandescence to probe the sublimation properties of soot,” at *Combustion Institute/Canadian Section Spring Technical Meeting*, Toronto, Canada, May 14–17, 2018 (6 pp.).
- C17. **Grauer, S.J.**, P.J. Hadwin, and K.J. Daun, “Chemical species tomography with self-similar covariance as hierarchical Bayesian inference,” at *9th International Conference on Inverse Problems in Engineering*, Waterloo, Canada, May 23–26, 2017 (8 pp.).
- C16. Sipkens, T.A., P.J. Hadwin, **S.J. Grauer**, and K.J. Daun, “Applying model selection to laser-induced incandescence,” at *9th International Conference on Inverse Problems in Engineering*, Waterloo, Canada, May 23–26, 2017 (16 pp.).
- C15. **Grauer, S.J.**, B.M. Conrad, R.B. Miguel, and K.J. Daun, “Assessment of a novel optical diagnostic to quantify emissions from a heated methane plume,” at *Combustion Institute/Canadian Section Spring Technical Meeting*, Montreal, Canada, May 15–18, 2017 (6 pp.).
- C14. Tsang, R.W., **S.J. Grauer**, and K.J. Daun, “Development, calibration, and testing of a tomographic open-path hydrocarbon detection system,” at *Combustion Institute/Canadian Section Spring Technical Meeting*, Waterloo, Canada, May 10–12, 2016 (6 pp.).
- C13. **Grauer, S.J.**, P.J. Hadwin, and K.J. Daun, “An analysis of prior information in Bayesian tomographic reconstruction,” at *1st Thermal Fluids Engineering Summer Conference*, New York, NY, Aug. 9–12, 2015 (11 pp.).
- C12. Tsang, R.W., **S.J. Grauer**, and K.J. Daun, “Development of an open-path hydrocarbon detector for tomographic mass flux estimation,” at *Combustion Institute/Canadian Section Spring Technical Meeting*, Saskatoon, Canada, May 11–14, 2015 (7 pp.).

## Abstracts

- C11. **Grauer, S.J.**, and A.M. Steinberg, “Direct background-oriented schlieren tomography” at *73rd Annual Meeting of the APS Division of Fluid Dynamics*, Seattle, WA, Nov. 23–26, 2019.
- C10. Daun, K.J., **S.J. Grauer**, P.J. Hadwin, and T.A. Sipkens, “Chemical species tomography in the Bayesian framework,” at 34th AIAA Aerodynamics Measurement Technology and Ground Testing Conference, Atlanta, GA, Jun. 25–29, 2018.<sup>1</sup>
- C9. Sipkens, T.A., **S.J. Grauer**, P.J. Hadwin, and K.J. Daun, “Predicting the heat of vaporization of iron at high temperatures using TiRe-LII and Bayesian model selection,” at *8th International Workshop on Laser-Induced Incandescence*, Munich, Germany, Jun. 10–13, 2018.
- C8. **Grauer, S.J.**, “Model error reduction in quantitative gas detection with hyperspectral imaging,” at *Telops 13th Annual Workshop on Hyperspectral Imaging*, Munich, Germany, Oct. 16 2017.
- C7. **Grauer, S.J.**, P.J. Hadwin, and K.J. Daun, “An a priori approach to assessing a Bayesian design-of-experiment procedure,” at *29th Inverse Problems Symposium*, Lexington, VA, Jun. 5–7, 2016 (3 pp.).
- C6. **Grauer, S.J.**, P.J. Hadwin, and K.J. Daun, “Basis function selection for Karhunen–Loève laser absorption tomography,” at *28th Inverse Problems Symposium*, East Lansing, MI, May 31–Jun. 3, 2015 (3 pp.).

## Posters

- C5. **Grauer, S.J.**, J. Emmert, A.M. Steinberg, S. Wagner, and K.J. Daun, “High-speed inference of absorbance data for absorption spectroscopy,” at *Gordon Research Conference on Laser Diagnostics in Energy and Combustion Science*, Les Diablerets, Switzerland, Jun. 23–28, 2019.
- C4. **Grauer, S.J.**, A. Unterberger, T.A. Sipkens, A.M. Kempf, K.J. Daun, and K. Mohri, “Background-oriented schlieren tomography for instantaneous 3D combustion imaging,” at *37th International Symposium on Combustion*, Dublin, Ireland, July 29–Aug. 3, 2018.<sup>2</sup>
- C3. Menser, J. **S. Grauer**, A. Unterberger, A. Kempf, and K. Mohri, “Volumetrical imaging of the Cambridge Flame using tomography, background-oriented schlieren and high-speed imaging,” at *CENIDE-Konferenz 2018*, Duisburg, Germany, Feb. 19, 2018.
- C2. Miguel, R.B., **S.J. Grauer**, and K.J. Daun, “A survey of techniques for optical measurement of flare combustion efficiency,” at *PTAC Forum Advancing the Low Carbon Economy Through Innovation & R&D*, Calgary, Canada, Oct. 23, 2017.
- C1. Sipkens, T.A., P.J. Hadwin, **S.J. Grauer**, and K.J. Daun, “Bayesian model selection for laser-induced incandescence,” at *Gordon Research Conference on Laser Diagnostics in Combustion*, West Dover, VT, Aug. 6–11, 2017.

## INVITED TALKS

- T8. Pennsylvania State University, State College, PA, Feb. 18, 2020.
- T7. Auburn University, Auburn, AL, Jan. 15, 2020.
- T6. University of Manitoba, Winnipeg, MB, Jul. 15, 2019.
- T5. Georgia Institute of Technology, Atlanta, GA, Apr. 2, 2019.
- T4. University of Alabama, Tuscaloosa, AL, Mar. 6, 2019.
- T3. University of Waterloo, Waterloo, ON, Apr. 19, 2018.
- T2. University of Edinburgh, Edinburgh, UK, Jan. 23, 2018.

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<sup>1</sup>Invited talk.

<sup>2</sup>Presented by invitation at the Princeton–Combustion Institute Summer School on Combustion, Princeton, NJ, Jun. 24–29, 2018.

T1. University of Duisburg-Essen, Duisburg, Germany, Sep. 27, 2017.

ACADEMIC  
SERVICE

**Reviewer** *AIAA Handbook Chapter*, *Optics Express* (7 papers), *Applied Optics* (6 papers), *Journal of Physics: Conference Series* (3 papers), *Combustion and Flame* (2 papers), *Journal of Verification, Validation and Uncertainty Quantification* (2 papers), *Optics Letters* (2 papers), *Proceedings of the Combustion Institute* (2 papers), *Applied Sciences* (1 paper), *Infrared Physics & Technology* (1 paper)

*International Conference on Inverse Problems in Engineering* (5 papers, 57 abstracts, 20 poster abstracts), *Thermal Fluids Engineering Summer Conference* (3 papers)

**Mentor** Provided significant mentorship to Prof. Daun's graduate students (3 Ph.D., 3 M.A.Sc.): teaching object-oriented programming, techniques of inverse analysis, and aiding preparation for comprehensive exams.

**Supervisor** Created research projects for Georgia Tech students (1 M.S., 2 B.S.) resulting in MATLAB scripts that were added to Prof. Steinberg's tomography codes.

REFERENCES

- Prof. Adam Steinberg** (Postdoc supervisor) [adam.steinberg@gatech.edu](mailto:adam.steinberg@gatech.edu)  
Daniel Guggenheim School of Aerospace Engineering Georgia Institute of Technology
- Prof. Kyle Daun** (Ph.D. supervisor) [kjdaun@uwaterloo.ca](mailto:kjdaun@uwaterloo.ca)  
Department of Mechanical and Mechatronics Engineering University of Waterloo  
Waterloo Institute for Nanotechnology University of Waterloo
- Prof. Andreas Kempf** [andreas.kempf@uni-due.de](mailto:andreas.kempf@uni-due.de)  
Institute for Combustion and Gas Dynamics University of Duisburg-Essen  
Chair of Fluid Dynamics
- Prof. Khadijeh Mohri** [khadijeh.mohri@uni-due.de](mailto:khadijeh.mohri@uni-due.de)  
Institute for Combustion and Gas Dynamics University of Duisburg-Essen
- Prof. Keith Woodbury** [keith.woodbury@ua.edu](mailto:keith.woodbury@ua.edu)  
Department of Mechanical Engineering University of Alabama  
Alabama Industrial Assessment Center University of Alabama