Combining Fluid Dynamics, Statistics and Pattern Recognition in Bloodstain Pattern Analysis, to Quantify Spatial Uncertainty and Remove Human Bias,

by Attinger (ISU), De Brabanter (ISU), SF Chang (Columbia U) and Gillen (NIST)

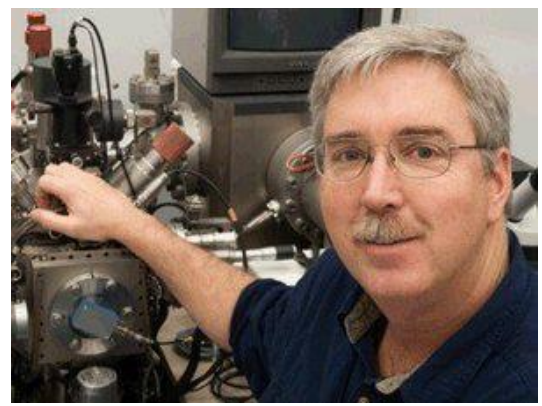
How was the crime committed?

Team

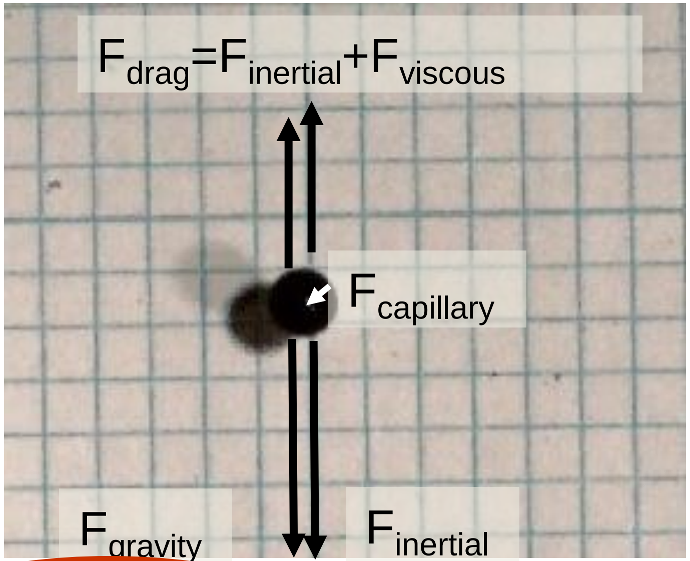
Kris de Brabanter
Iowa State U
Statistical Learning and
Mathematical Statistics

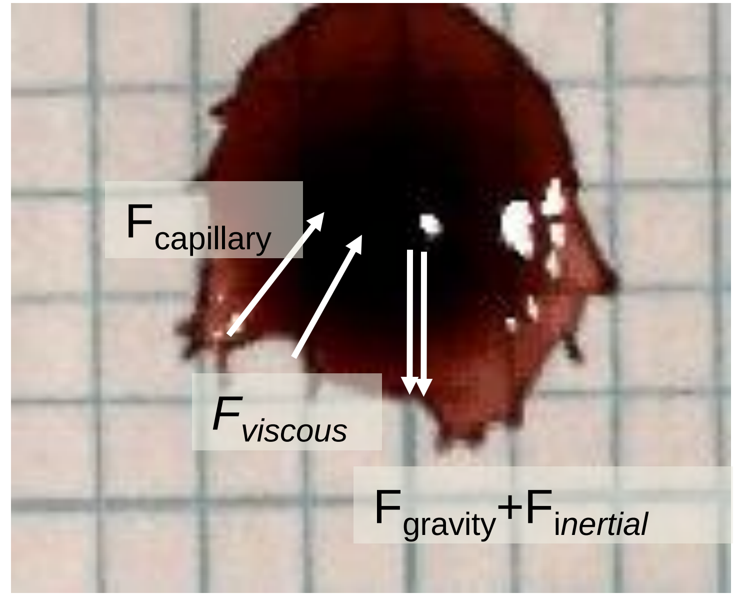
Shih-Fu Chang
Columbia U
Computer Vision and
Machine Learning

Attinger Daniel
Iowa State U
Fluid Mechanics and
Transport Phenomena



Greg Gillen
NIST
Trace analysis and
Inkjet Printing



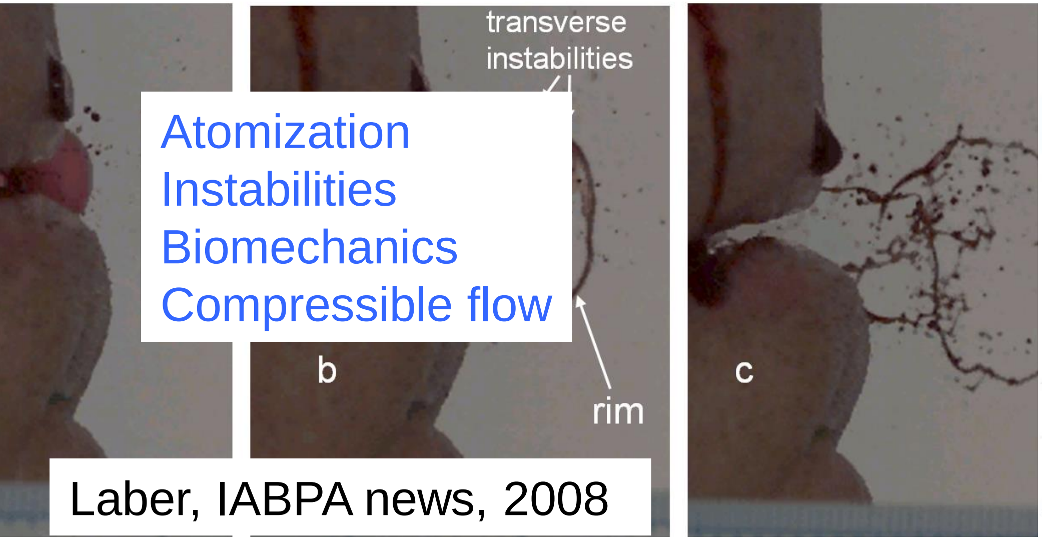


Dimensionless number	Definition	Magnitude in BPA	Ratio of Forces
Reynolds number	$Re=\rho vd/\mu$	0 to 100,000	Inertia to viscous forces, describes the drag during the flight of a drop and the impact of a drop on a surface
Weber number	$We=\rho v^2 d/\sigma$	0 to 1×10^7	Inertia to surface forces, describes jetting, impact and drop oscillations
Capillary number	$Ca=\mu v/\sigma$	0-8	Viscous to surface forces, describes wetting and imbibition
Bond number	$Bo=\rho d^2 g/\sigma$	0-5	Gravity to surface forces, controls spreading of large drops or streams; establishes the shapes of static drops
Froude number	$Fr=v^2/dg$	0 to 1×10^{12}	Inertia to gravity, controls spreading and flight of drops

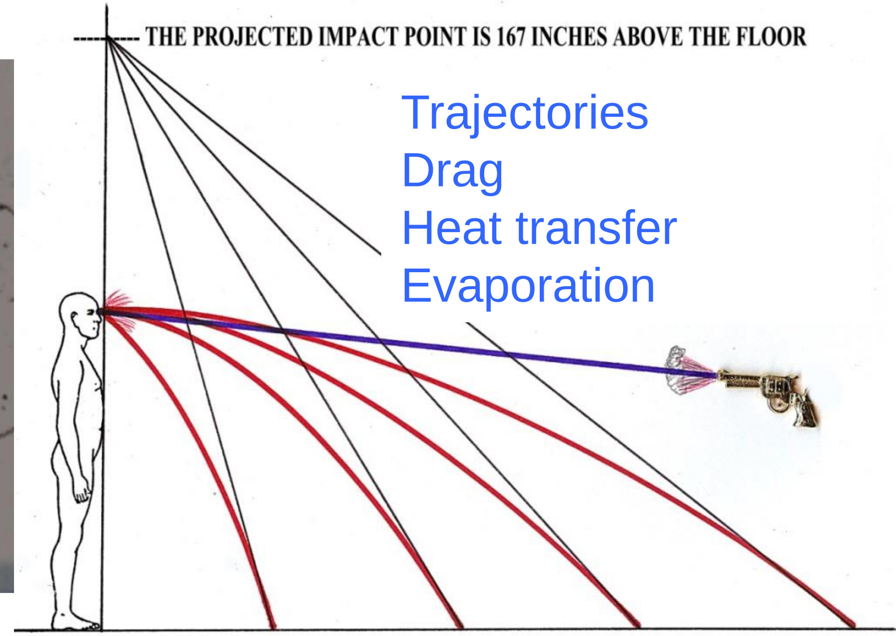
D. Attinger, C. Moore, A. Donaldson, A. Jafari, and H. A. Stone, Forensic Sci Int, 2013.

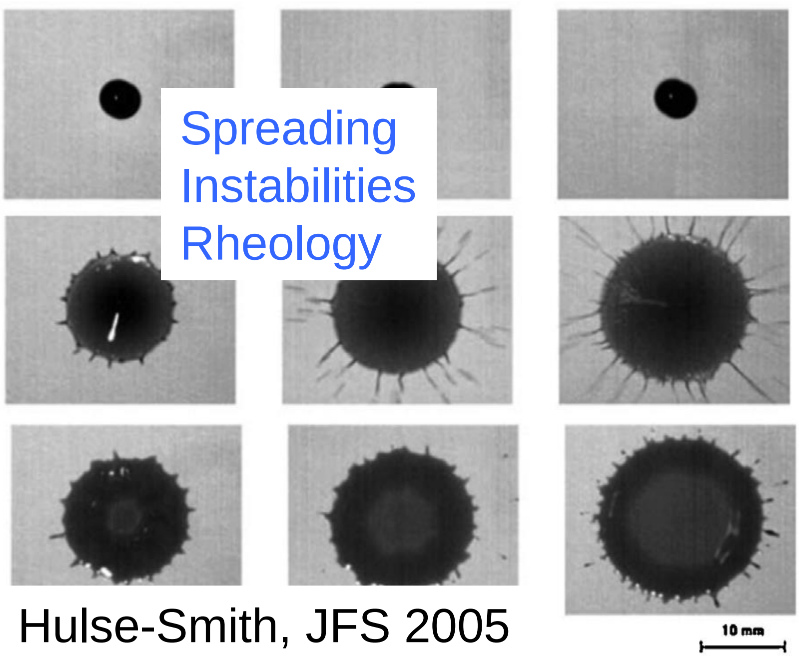
FD

BPA

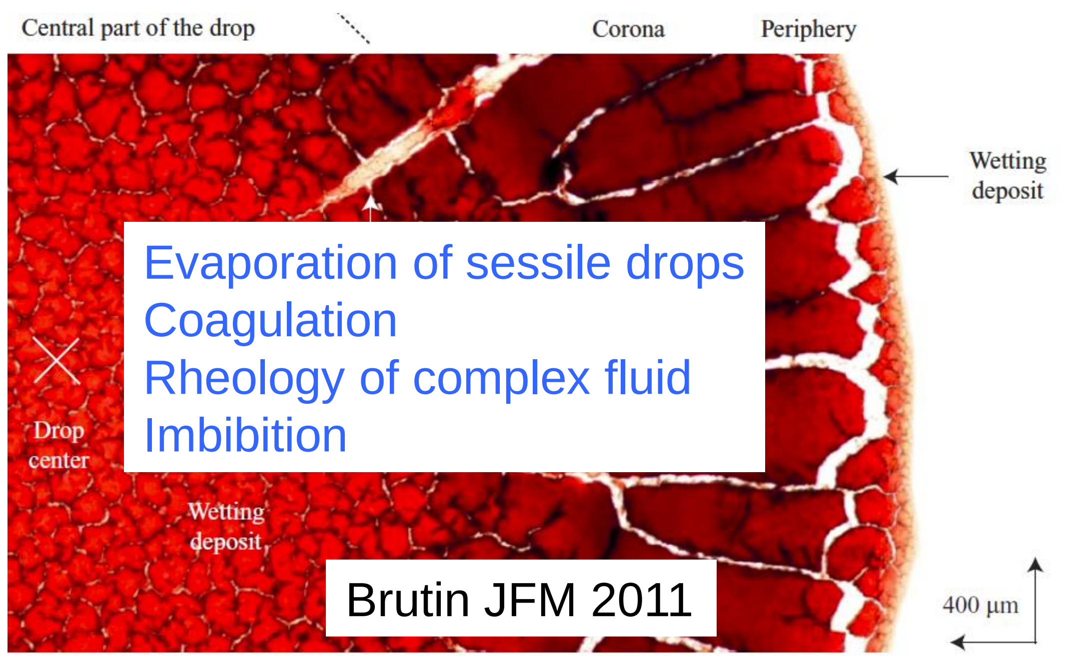


Laber, IABPA news, 2008



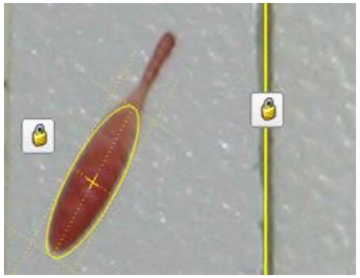


Hulse-Smith, JFS 2005

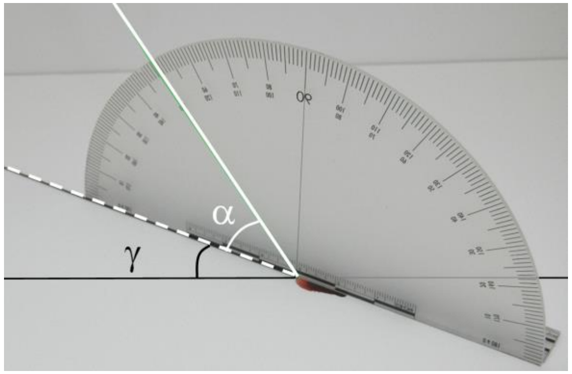


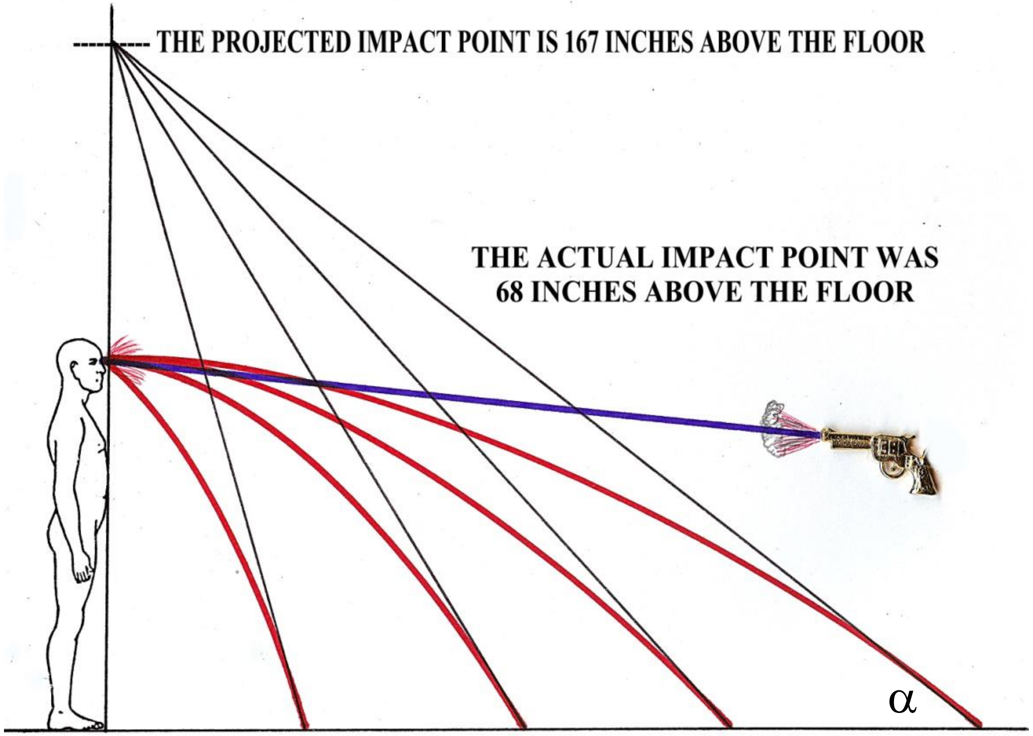
Brutin JFM 2011

Objective 1: Quantifying the uncertainty in the region of origin



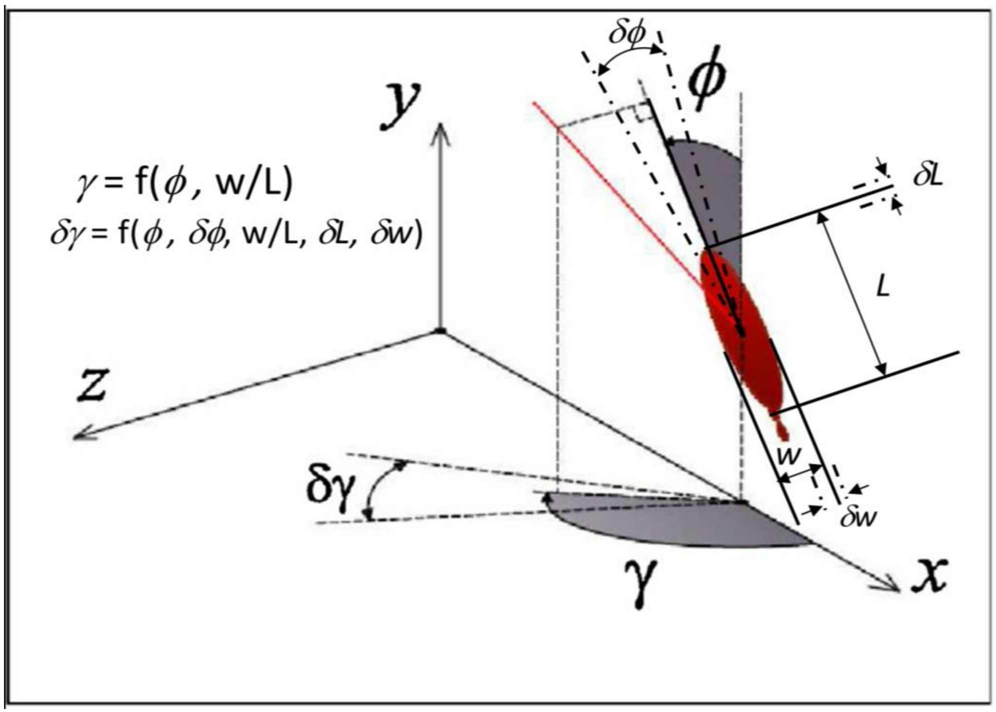
Width/Length= $\sin\alpha$

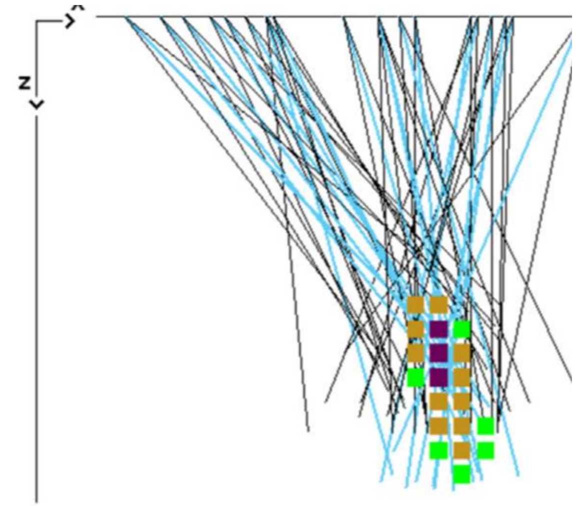




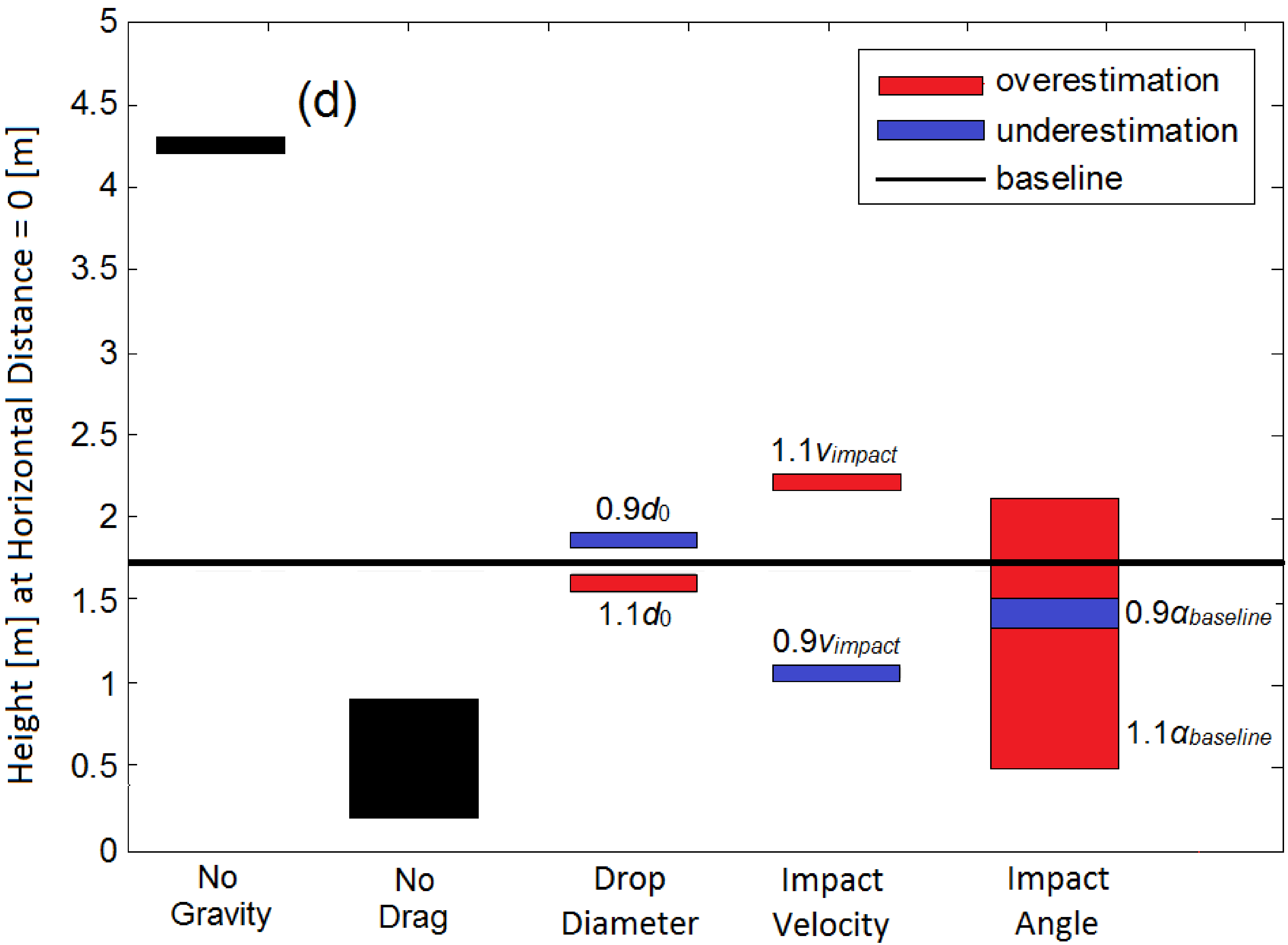
Courtesy of H MacDonell, Oct 2010

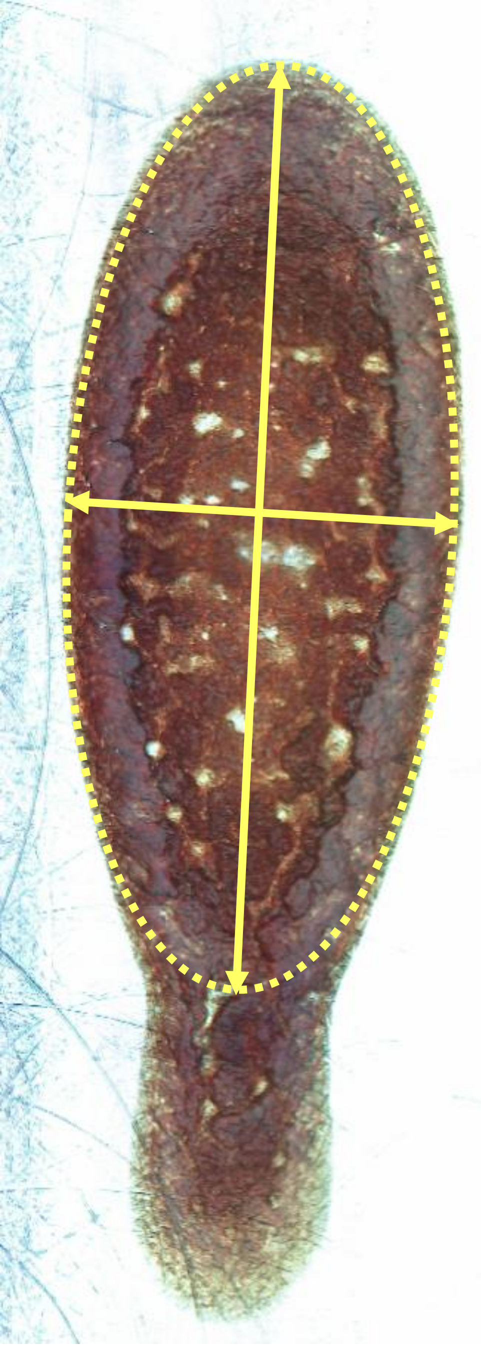
Objective 1: The team will develop algorithms for identification of the region of origin of a blood spatter that propagate the uncertainty and represent its spatial magnitude in a 3-D space

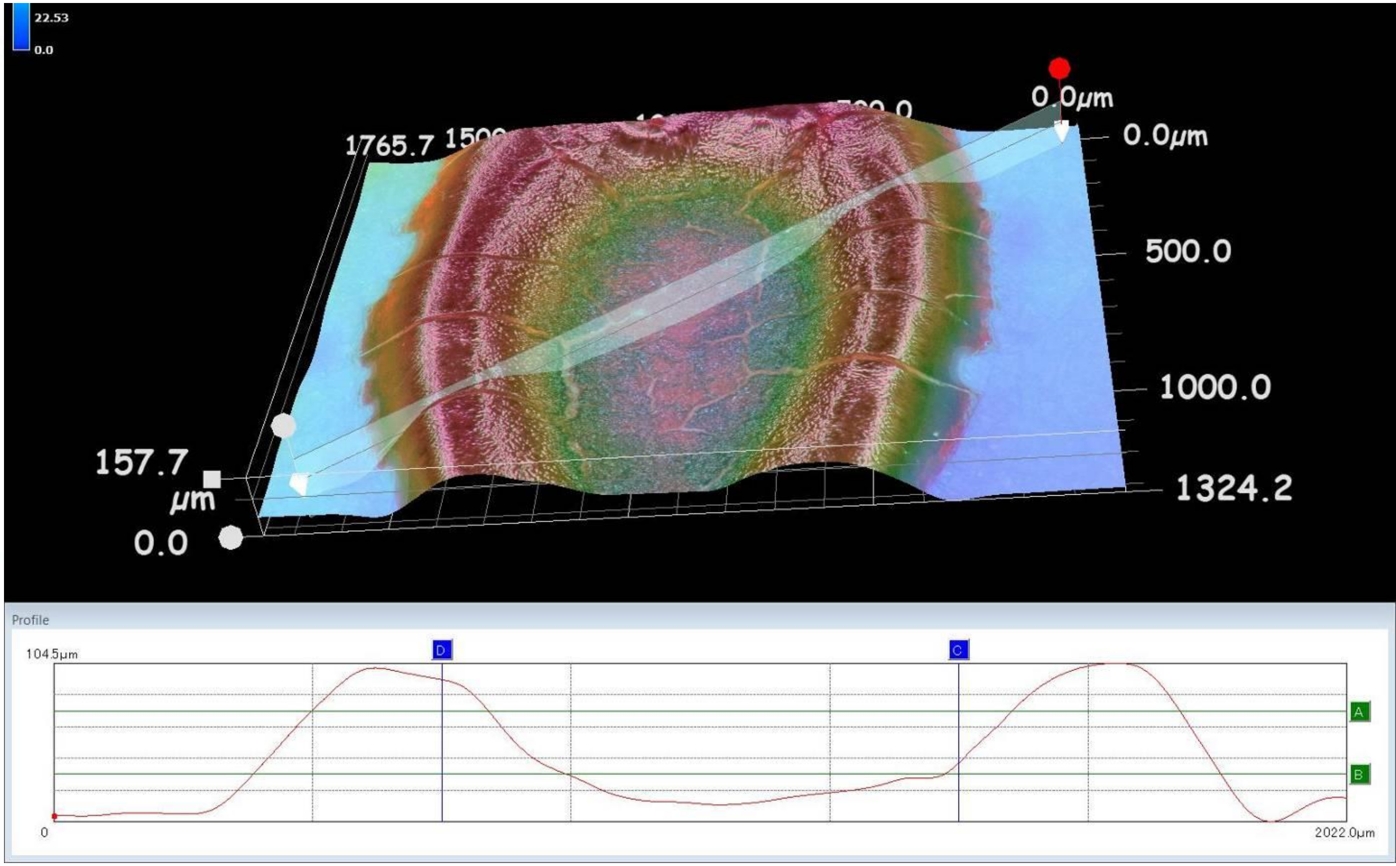




In year 1, the team will extend to 3D the propagation method of Camana [FSI 2013], which determines how uncertainties in the measurement of individual stains influence the determination of the region of convergence of a blood spatter,


(d)
overestimation
underestimation
baseline
Height [m] at Horizontal Distance = 0 [m]
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
$0.9d_0$
$1.1d_0$
$1.1v_{impact}$
$0.9v_{impact}$
$0.9\alpha_{baseline}$
$1.1\alpha_{baseline}$
No Gravity
No Drag
Drop Diameter
Impact Velocity
Impact Angle

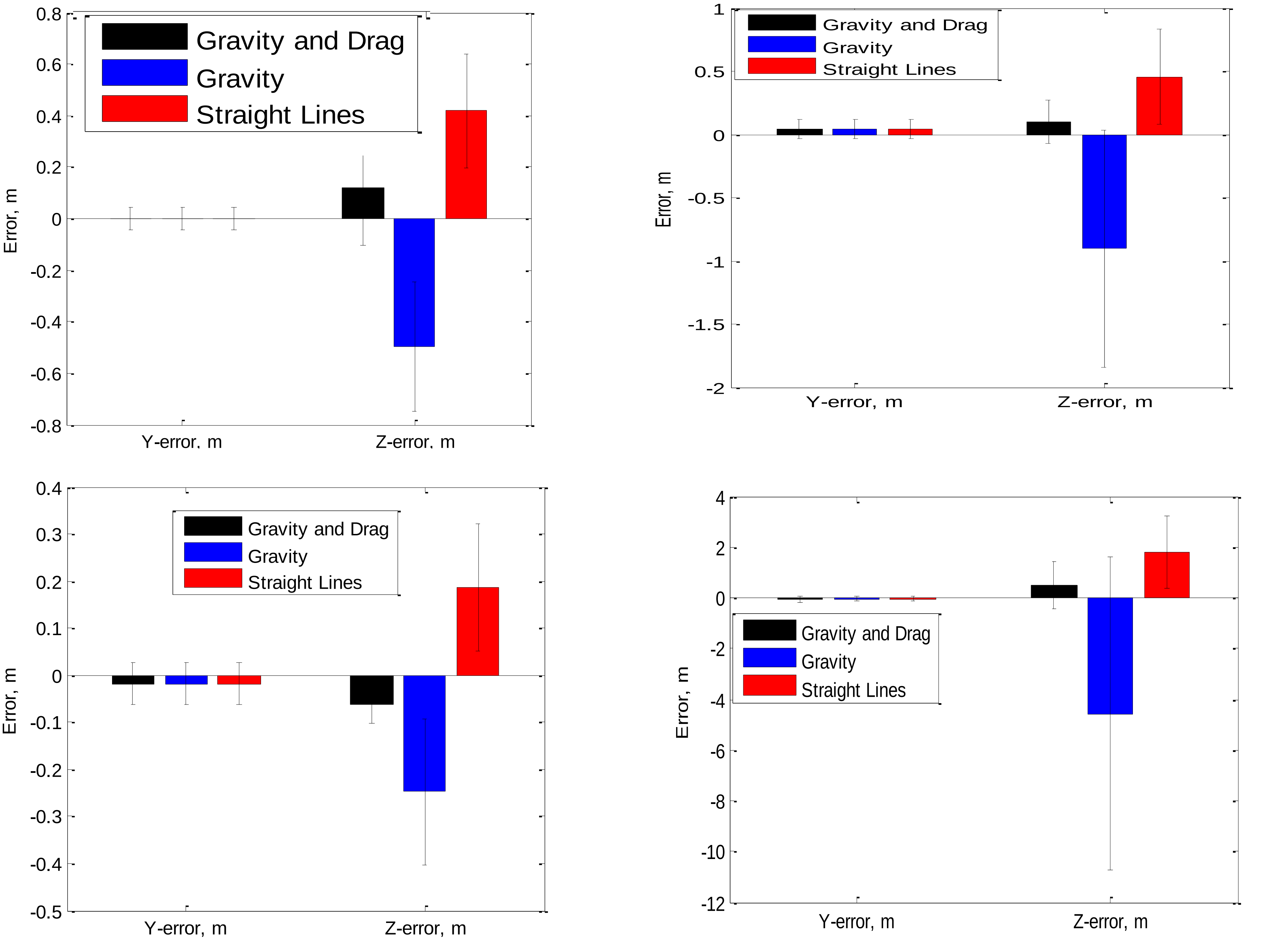




Stain volume by integration of droplet height

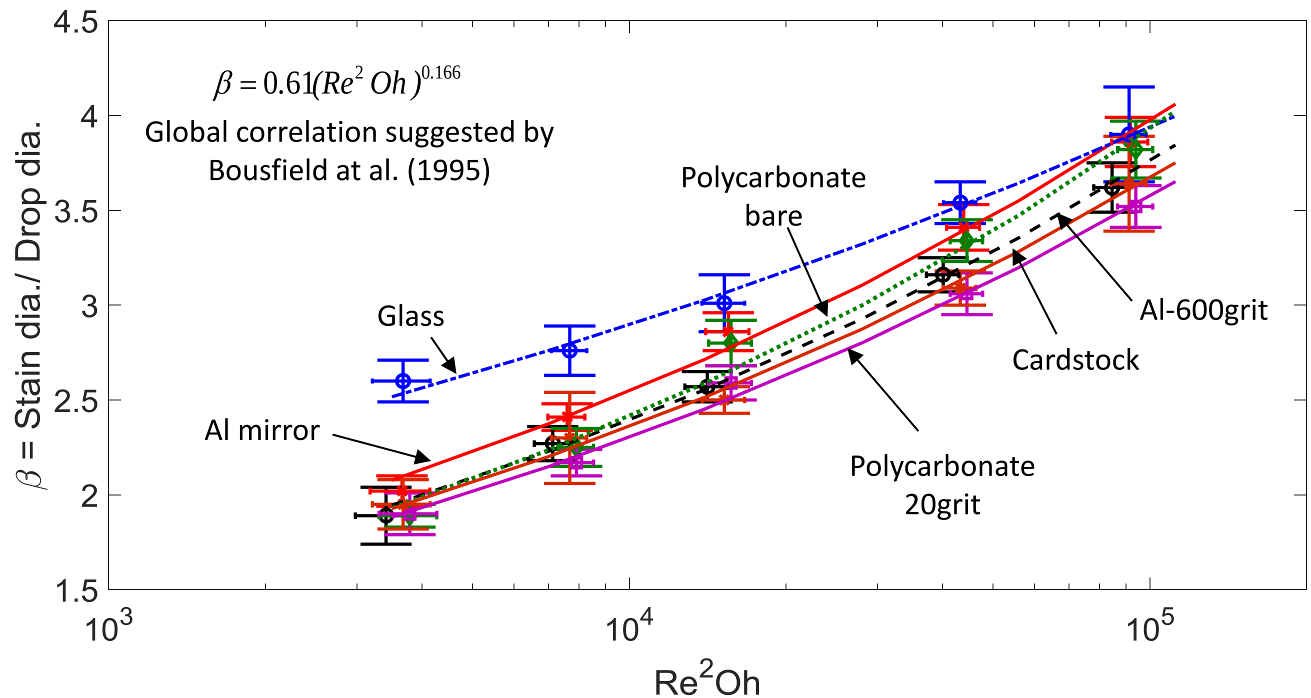
Drop volume proportional to stain volume.

Drop velocity from spreading correlations.



Gravity and Drag
Gravity
Straight Lines
Error, m
Y-error, m
Z-error, m
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
1
0.5
-0.5
-1
-1.5
-2
0.3
0.1
-0.1
-0.3
-0.5
4
2
-2
-4
-6
-8
-10
-12

target material influences spreading

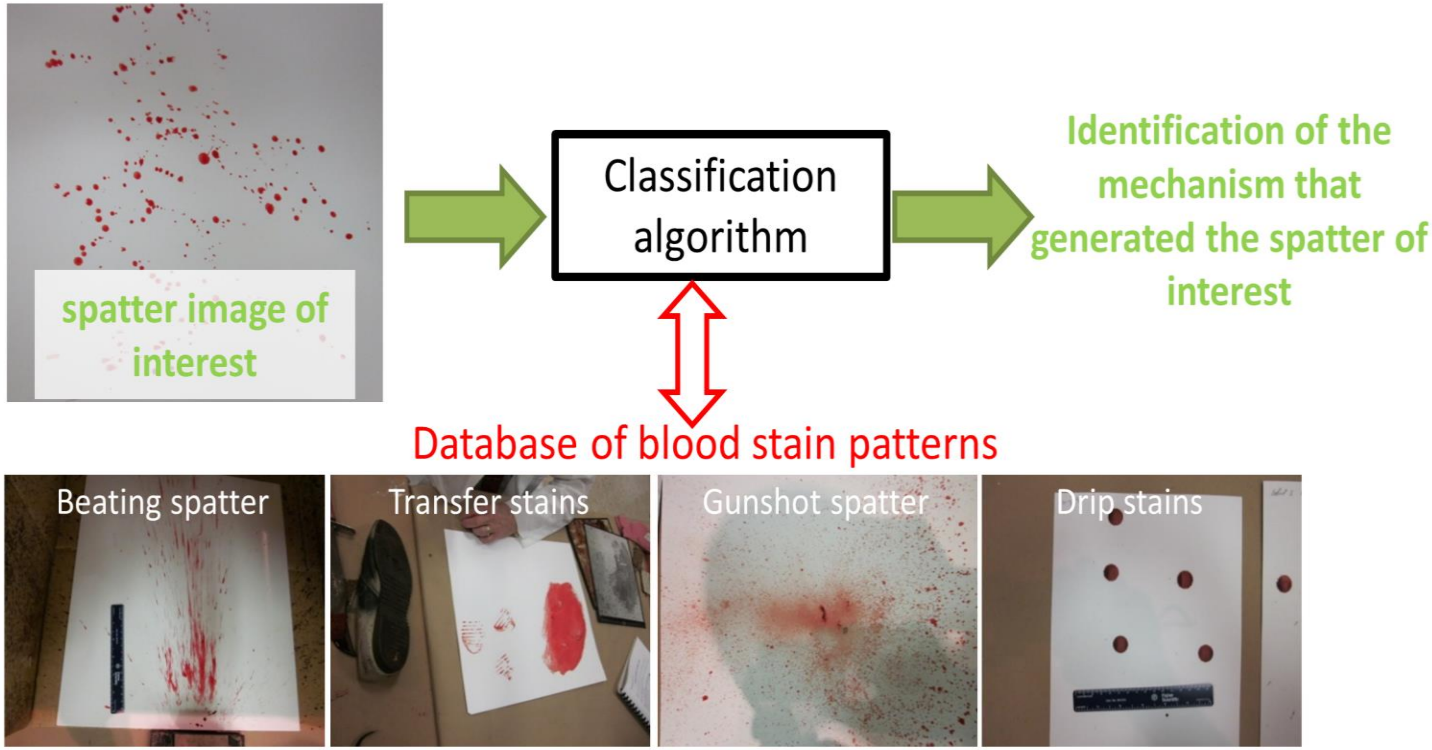


Substrate	Correlation
Glass	$b=0.8474(Re^2Oh)^{0.1334}$
Aluminum mirror	$b=0.4285(Re^2Oh)^{0.1934}$
Aluminum 600 grit	$b=0.3914(Re^2Oh)^{0.1965}$
Cardstock	$b=0.4019(Re^2Oh)^{0.1921}$
Polycarbonate bare	$b=0.3428(Re^2Oh)^{0.2118}$
Polycarbonate 20 grit	$b=0.3954(Re^2Oh)^{0.1912}$

- Correlations for each surface was evaluated based on the experimental results
- The spreading factor on glass at low Re^2Oh was more than 25% higher than those on other surface due to the static contact angle.
- The spreading factor on roughened surface was lower

S. Kim et al., Forensic Sci Int, 2013.

Objective 2: develop robust pattern recognition algorithms to identify the generation mechanism of an unknown bloodstain pattern



The classification will rely on a database of spatters produced under known conditions – including gunshot, cast-off, dripping blood, transfer stains. This will advance the state of the art, where classification is done by the human investigator. Here again the classification algorithm will provide automated interpretation and uncertainty quantification (Chang and De Brabanter).

Pattern recognition for bloodstain identification

- "Big data" problem since the number of bloodstain in a crime scene is (can be) massive
- So far, relatively simple classifiers have been used (Naive Bayes, KL, LDA, QDA)

  ✓ Simple and easy to use classifiers
  ✓ Can handle "Big data"

  - Rely on parametric assumptions on the distribution of the data (usually normality)
  - Most of them produces linear decision boundaries.

In this proposal we want to use state-of-the-art classification algorithms (SVM, random forest, etc.) suitable for large data sets while relaxing the underlying parametric distribution assumption of the data. These classifiers can produce linear and nonlinear decision boundaries.

We will use a technique called fixed-size least square support vector machines (De Brabanter *et al.* (2010)) to classify blood spatters. This technique is capable of handling several millions of data points on standard PCs.

De Brabanter K., De Brabanter J., Suykens J.A.K., De Moor B., Optimized Fixed-Size Kernel Models for Large Data Sets, Computational Statistics & Data Analysis, vol. 54, no. 6, Jun. 2010, pp. 1484-1504

How the research will expand on NIST work

NIST Collaborator Dr. Greg Gillen is a Supervisor Research Chemist and Group Leader at NIST.

Dr. Gillen invited Attinger for a talk and research discussion in 2003, on droplet generation for analytical purposes.

The two scientists have maintained a scientific correspondence ever since. Dr Gillen has expertise related to trace analysis and inkjet printing, both domains being relevant to the estimation of drop impact conditions for trajectory reconstruction.

Gillen will develop expertise in

1. inkjet printing of bloodstains of controlled volume on e.g. fabric, to assist with stain formation on absorbing surfaces.
2. characterization of the volume of a blood droplets using analytical method, to provide initial conditions for the trajectory reconstruction algorithms of Attinger

https://en.wikipedia.org/wiki/Pregnancy_test#/media/File:PositivePregnancyTest.JPG

Goals are to produce rational and automatic methods for bloodstain pattern analysis,
to allow the rational estimation of the uncertainty, and
the rational identification of the spatter mechanism

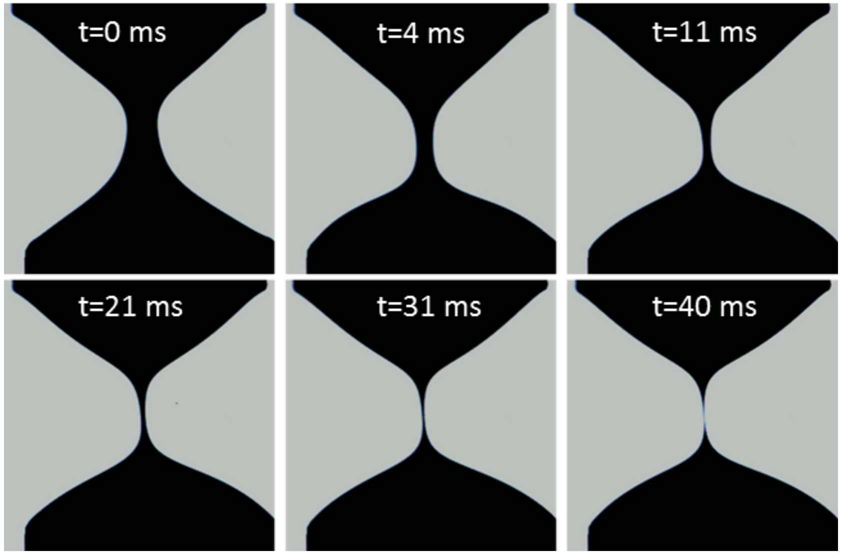
Process for inserting the work into the crime laboratory

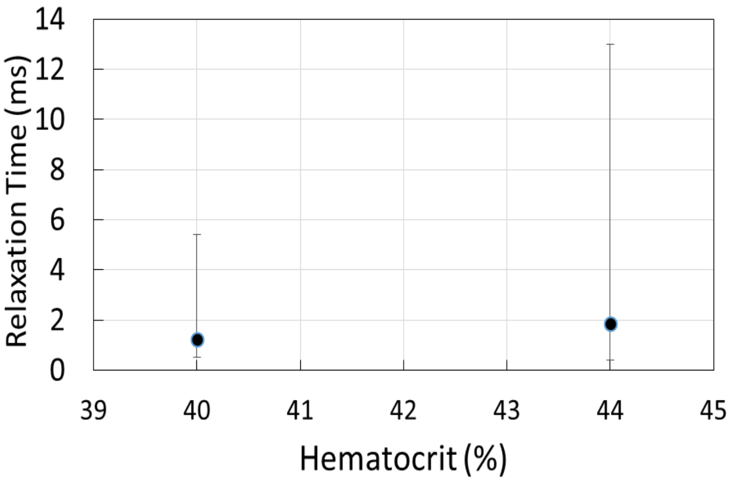
Currently, the reconstruction of trajectories relies on manual selection of stains; the identification of the mechanism causing a blood spatter (gunshot, beating, transfer) relies on the judgement of a human analyst.

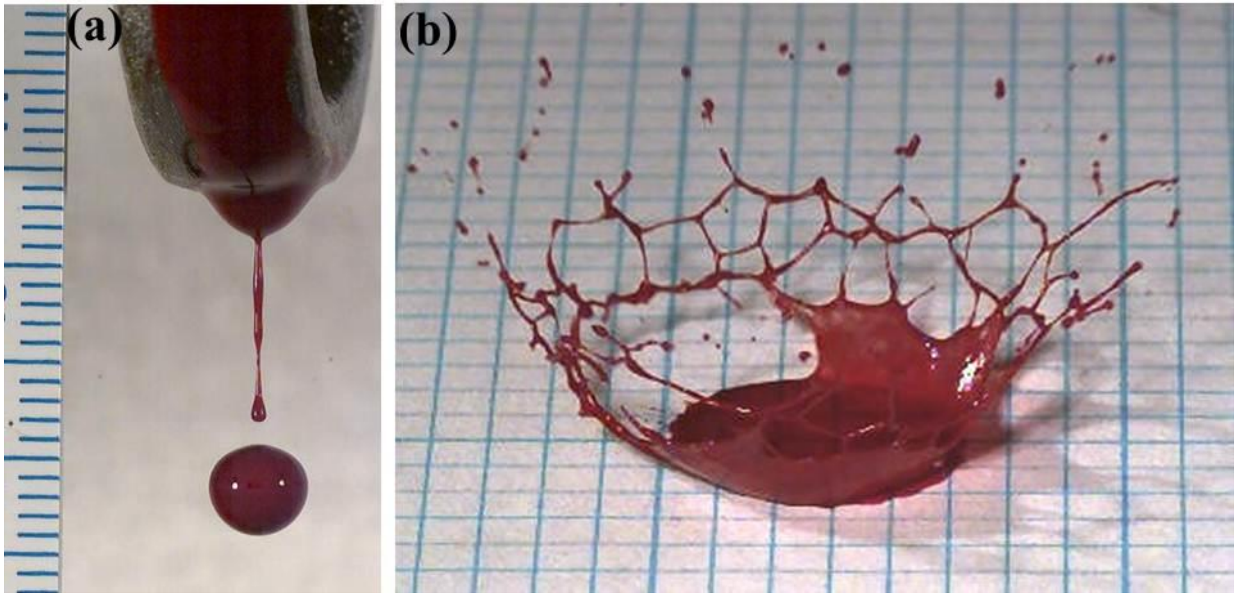
The proposed research, if funded, will automatize both processes and remove (or strongly reduce) human intervention and bias.

PI Attinger has taught advanced bloodstain pattern analysis to the Crime Scene Analysts of Las Vegas/Henderson, in the graduate program of the University of the West Indies, and is presently setting up a program to educate criminal police forces in Switzerland. He is a court-certified expert in bloodstain pattern analysis. He has the outreach and contacts to expose crime laboratories to these new techniques, when ready.

Blood viscosity: viscoelasticity







A. Kolbasov, P. Comiskey, R. P. Sahu, S. Sinha-Ray, A. L. Yarin, B. S. Sikarwar, S. Kim, T. Z. Jubery, and D. Attinger, "Blood Rheology in Shear and Uniaxial Elongation," *Rheological Acta,* under revision 2016.

Application of statistics/probability to reducing or clarifying uncertainty

Current methods to identify the region of origin of a blood spatter neglect key physics such as gravity and drag, and do not allow rational estimation of the uncertainty.

Very recently, physics-based algorithms have been developed to predict the region of origin of the stains by inspection of a blood spatter [5-7].

This is a significant advance which makes it possible to estimate and propagate uncertainties in the determination of the region of origin. The team will therefore develop algorithms for identification of the region of origin of a blood spatter that propagate the uncertainty and represent its spatial magnitude in a 3-D space (Objective 1).

Brief motivation

Identifying the 3D region of origin of a blood spatter in a crime scene involves the backward reconstruction of trajectories of stains selected among the 10-1000+ stains of a spatter.

Currently used reconstruction methods assume straight trajectories, hereby neglecting the effect of drag and gravity on the droplet's motion.

This **oversimplification introduces significant and difficult/impossible-to-quantify uncertainties in the estimation of the region of origin** : "Such errors are significant enough to wrongly conclude that a person was standing when in fact they may have been sitting" [ref. 15 of proposal].

Also, Bloodstain Pattern Interpretation still relies on human comparison between the patterns observed at the crime scene with those learned in BPA classes [4].

PI Attinger at Iowa State has developed methods [5-7] to include drag and gravity in the reconstruction of trajectories. Collaborator SF Chang (H-index 93) and Brabanter (ISU) are experts in pattern recognition.