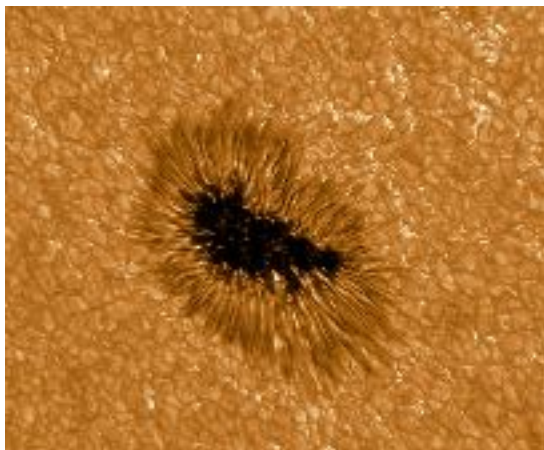


Lecture course: Computational Fluid Dynamics



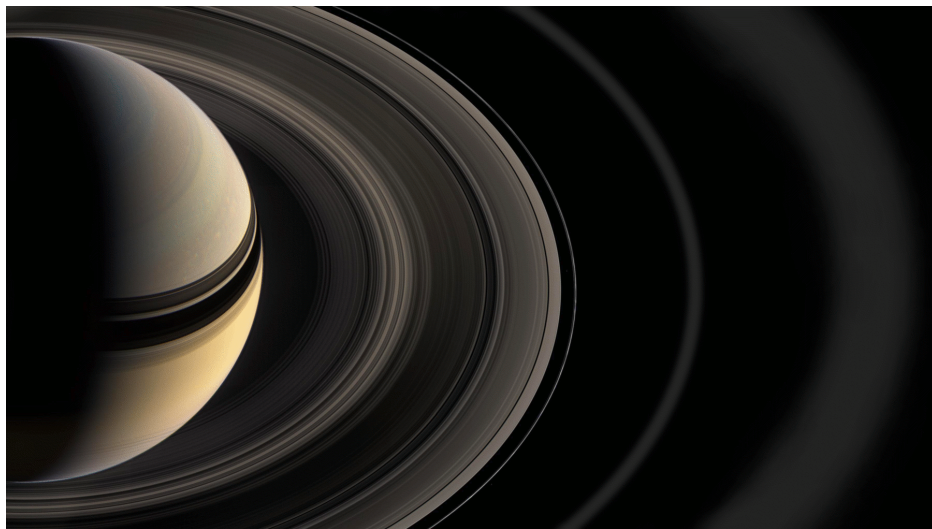
Daniel M. Siegel
Perimeter Institute for Theoretical Physics
Department of Physics, University of Guelph



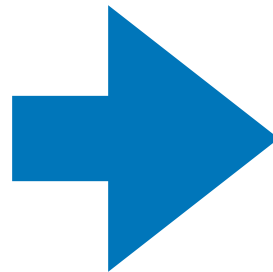
Lecture I: Preliminaries

Astrophysical ‘fluids’: ubiquitous in the Universe on all scales

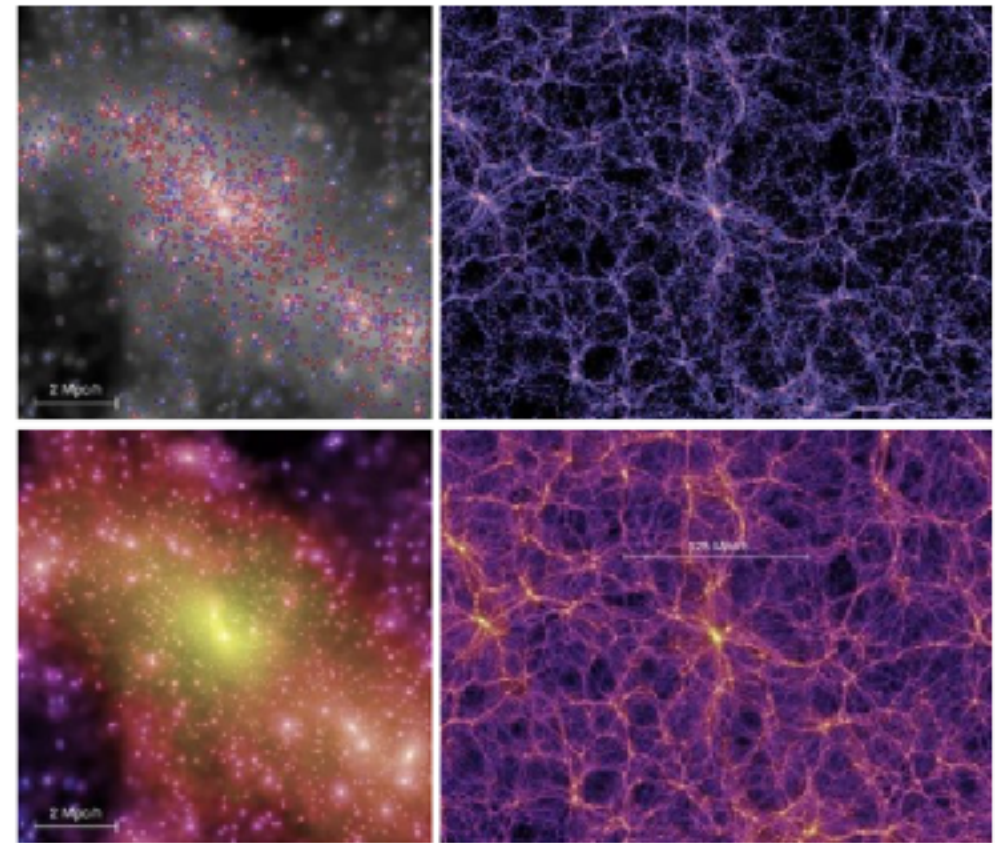
Dust rings of Saturn



Credit: NASA/JPL-Caltech/Space Science Institute



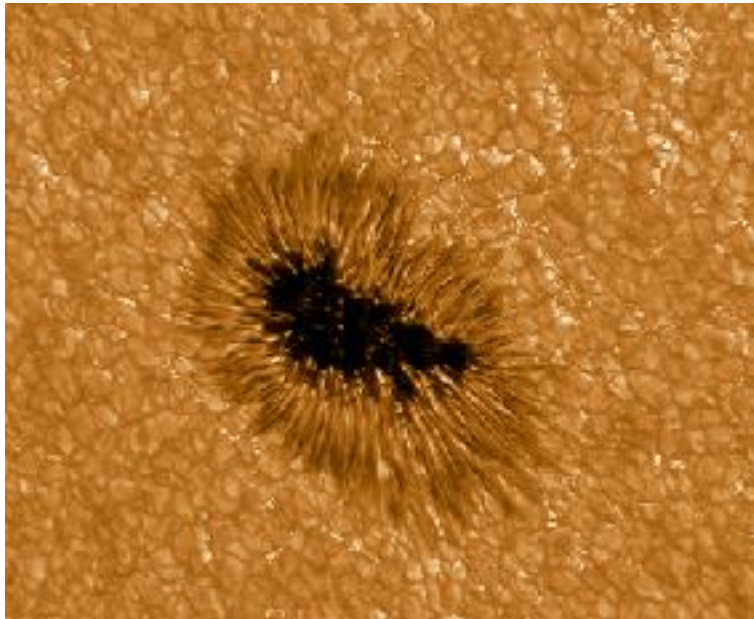
Matter distribution of the Universe



Credit: Springel et al. 2005, Nature, 435, 629

Astrophysical ‘fluids’: a few more examples...

Solar & stellar astrophysics



Credit: Leibniz Institute for Solar Physics (KIS)

Supernova remnants



Credit: NASA, STScI, ESA

Interstellar medium



Credit: NASA

Tidal disruption events



Credit: NASA / CXC / M. Weiss

Neutron-star mergers



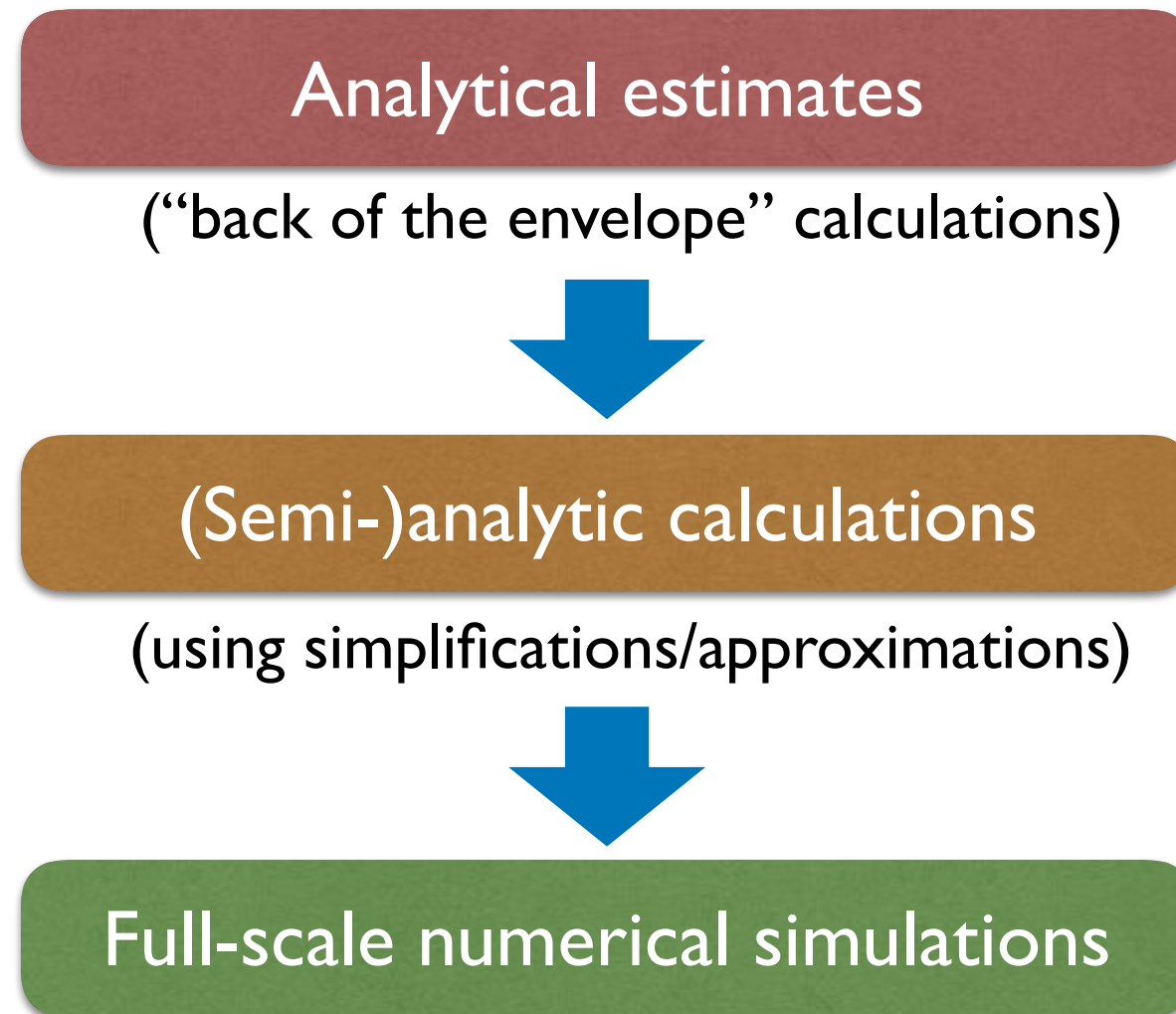
Credit: Robin Dienel, Carnegie Institution for Science

Astrophysical fluid dynamics

- Astrophysical fluid flows central to understanding our universe
 - equations of gas/plasma dynamics (**hydrodynamics**)
(+ **gravity** and **microphysics**: chemistry, nuclear & atomic physics, EM fields, etc.)
- Receive information about the universe based on EM radiation that is reprocessed as it travels toward us
 - equations of **radiation transport**
- We now also receive information via gravitational waves and high-energy particles
 - **multi-messenger astrophysics**

Interpretation of observational data

Theoretical interpretation of observational data (stages of refinement):

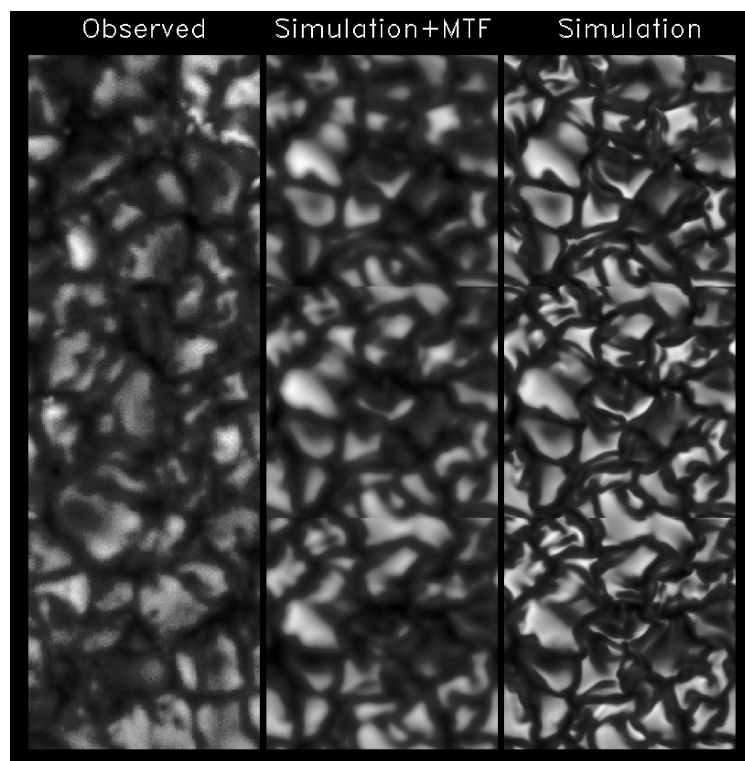


experiment
'substitute'
↔

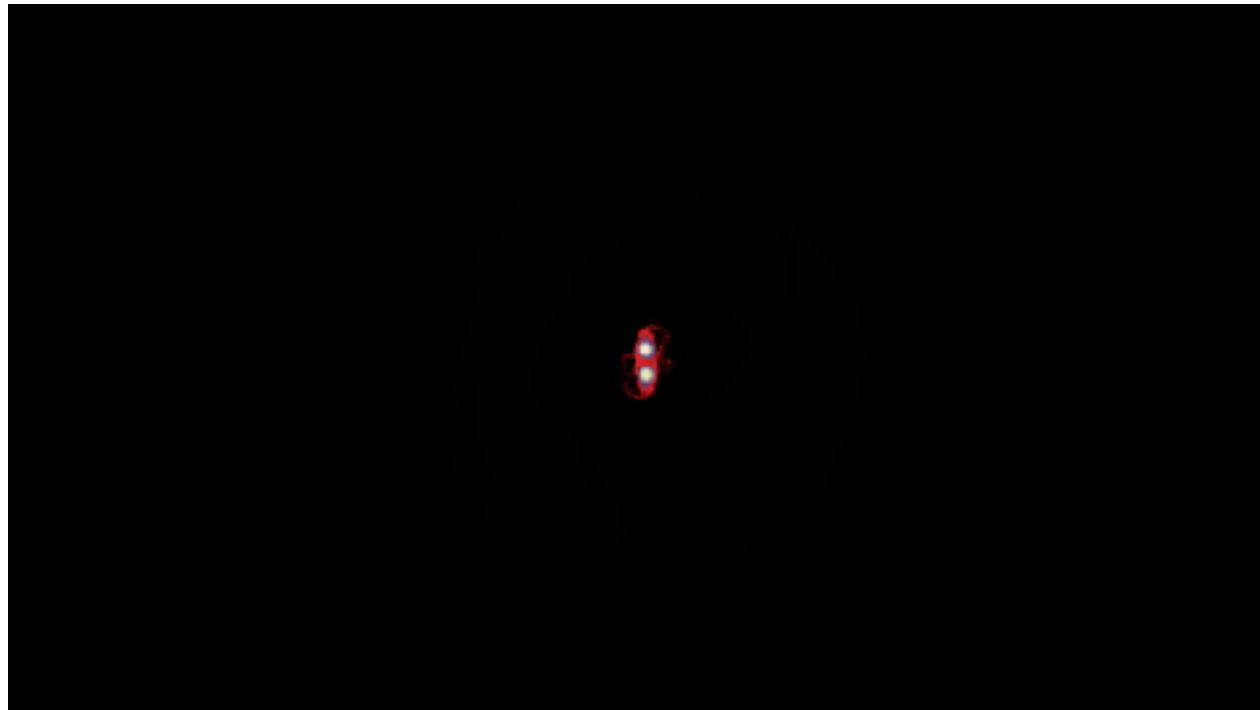


Simulations can achieve amazing things...

Solar granulation
(radiation hydrodynamics)



Credit: Stein+ 1998, ApJ 499, 914



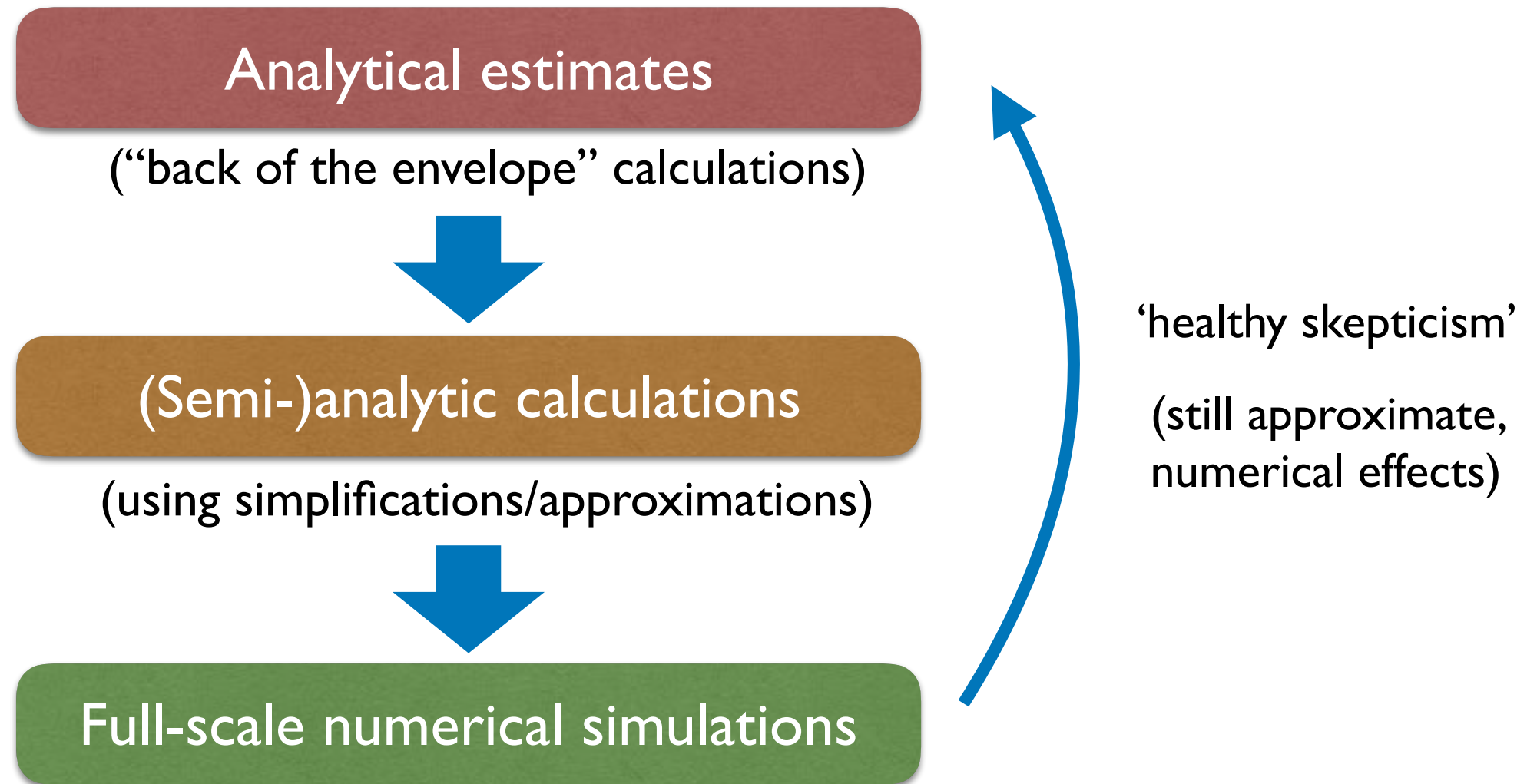
Movie credit: Ciolfi+, Siegel 2017, PRD 95, 063016



Credit: Springel et al. 2005, Nature, 435, 629

Interpretation of observational data

Theoretical interpretation of observational data (stages of refinement):



experiment
'substitute'
↔



Expectations of expectations

reduce complexity and provide stability to social systems (Luhmann)

...so let's talk about expectations:

Course contents and ‘mechanics’


- For course outline and policies, please see:
<https://www.physics.uoguelph.ca/course-outlines/special-topics-astrophysics-numerical-hydrodynamics-phys7900>
- Course website (repository with course material):
<https://github.com/dmsiegel/computational-fluid-dynamics-course.git>
- ‘Interpolation’ between applied mathematics, physics, astrophysics
‘blackboard’ lectures, *hand-written* lecture notes
- Homework (30% final grade):
 Problem sets with analytical problems
 Project components with hands-on implementations:
 - finite difference schemes and explore their properties
 - an ‘exact’ Riemann solver for the Euler Equation
 - a Godunov-type scheme for Newtonian hydrodynamics
- Exam (70% final grade): date & time TBD

Course contents and ‘mechanics’

- Contents

1. Basic Notions of Partial Differential Equations
2. Basic Equations of Computational Fluid Dynamics
3. Finite Difference Methods for PDEs
4. Properties of conservation laws (theoretical background)
5. Riemann problem for the Euler Equations
6. Numerical schemes for conservation laws
7. Approximate Riemann solvers
8. Source terms and higher dimensions
9. Outlook: a primer on discontinuous Galerkin methods

**Very general, directly relevant
for Einstein's equations as
well!**



Course contents and ‘mechanics’

- References

This course draws from all the below listed recommended literature

Numerical Methods:

- E.Toro: Riemann Solvers and Numerical Methods for Fluid Dynamics (Springer, 3rd edition, 2009)
- R. Leveque: Finite Volume Methods for Hyperbolic Problems (Cambridge Univ. Press, Cambridge Texts in Applied Mathematics, 2002)

More mathematically inclined literature:

- D. Kröner: Numerical Schemes for Conservation Laws (Wiley, 1997)
- L. Evans: Partial Differential Equations (Graduate Studies in Mathematics, American Mathematical Society, 2nd edition, 2010)

Other useful literature:

- A. Anile: Relativistic fluids and magneto-fluids (Cambridge Univ. Press, 1990)
- P. Bodenheimer, G. Laughlin, M. Rozyczka, H. Yorke: Numerical Methods in Astrophysics (Taylor & Francis, 2007)
- R. Leveque: Finite Difference Methods for Ordinary and Partial Differential Equations (SIAM, 2007)