Slide 1 – Title and cover page

Welcome and Title explanation

- Radiation hydrodynamics:
  In RHD considering radiation to be a massless relativistic fluid which in certain conditions has great influence on non–relativistic matter. This is called radiative transfer.
  An analogous strategy can be applied as for classical hydrodynamics in which the microscopic behavior of particles is averaged over to recover macroscopic dynamics of the whole as well as the conservation laws of the descriptive variables.
  RHD combines classical hydrodynamics and this radiative transfer to describe this interaction of the two fluid descriptions.

The cover page shows the numerical result of this theory. It represents the infrared radiation density within a molecular cloud, I'll tell more about these simulations later...

- Star formation: the process of the creation of protostars and eventually stars

  Stars are the probably best researched astronomical objects in the Universe.

  Partially because one is right in our neighborhood.

  The Sun is considered to be the essential energy source for the existence of life on Earth.

  The energy is gained by fusion in the star's core. It combines H atoms to He and so on... this process also enriches the Universe with metals (up to Fe; essential for the formation of other structures).

  The other reason is that stars are almost the only light source we can see either directly or indirectly through the thermal emission of heated gas or dust around them.

  Exceptions are only two: synchrotron radiation from particles in magnetic fields and emission from quasars as a result of the release of gravitational energy as mass spirals into the center of accretion disks.

Slide 2 – Structure

Explain structure of the presentation

- Hydrodynamics
- Radiative transfer
- bring both components together
- Basics in numerical methods
- Molecular clouds
- Star formation process
- Simulations

Slide 3 – Hydrodynamics

- Fluid is a gas or liquid composed of molecules that collide with each other and different kinds of matter.
  This means that fluids are actually discretized on a microscopic level.
- However hydrodynamics assumes otherwise.
  The fluid is here described as a continuum where its properties like density, flow velocity, pressure and temperature are everywhere well–defined...

- This assumption is applied on the Boltzmann equation which describes the displacement of these discrete fluid elements in phase space.
  It is the basic equation from which the dynamics of a fluid are recovered.
- In the application of the molecular chaos assumption, we see that the source or collision integral is zero. This is equal to say that the fluid elements are close to local thermodynamical equilibrium where collisions average out overall.
- The averages over phase space volumes of the Boltzmann equation recovers the foundational axioms of fluid dynamics on a macroscopic level.
- These equations express the conservation of mass, momentum and energy.
  The first equation is also known as Continuity equation, the second is an incorporation of Newton's Second Law of Motion and the third is also known as First Law of Thermodynamics.

- The fundamental quantity to describe a field of radiation is the radiation specific intensity.
- The energy flowing through an area is proportional to the solid angle about the flow direction in a certain time and frequency interval. The proportionality factor is described by the radiation specific intensity.
- Analogously to the classical hydrodynamics case, a Boltzmann equation corresponding to photons leads to the radiative transfer equation.
  However, radiation cannot be assumed to be continuous as before, which means we have to include the collision or source integral.
- This can be derived by means of an example...

- Let's consider a source emitting radiation towards a cloud laced with dust and behind that cloud a detector measuring the radiation coming through the cloud.
  Obviously, due to experience here on Earth when you look at the sky it can happend that the light of the Sun is blocked or at least weakened by clouds.
- In our example the light can interact with the cloud through several processes.
  Scattering and absorption weaken the intensity. Thermal emission on the other hand can contribute to the intensity.

- This results in the Boltzmann equation for a relativistic fluid and its moments expressing conservation laws for energy and momentum.
- They are very similar to the classical hydrodynamics equations, which is why I showed them in the first place.
- All these equations are hyperbolic partial differential equations and describe the conservation of a particular variable.

Slide 6 – Numerical Methods

- Since all the equations have the same form, it is easy to construct a numerical scheme to solve them all.
  Of course, there are slight differences such as source terms which have to be solved individually.
- It was Godunov in 1959 who thought of such a numerical scheme for conservation laws.
  The main idea is to either discretize an analytical function or to already start from discretized data.
  This can be done such that one obtains structured, that is rectangular, or unstructured grid cells.
- The integral form with the discretized data already recovers the numerical scheme.

Slide 6 – Numerical Methods

- Godunov himself predicted that this scheme and schemes using Godunov–like strategies can actually never be higher than first order.
- However, there are options to improve this scheme. For example to already start with different discretizations, for example with piecewise linear interpolations or even piecewise parabolic interpolations.
- This in turn requires modifications in the Riemann solver.

Slide 7 – AMR

- The simulations I will present, were performed with RAMSES, which is a easy choice if your supervisor is actually its creator.
- It is the

Slide 8 – Molecular Clouds – Eagle Nebula

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Slide 9 – Molecular Clouds – Pillars of Creation

Slide 10 – Collapse to protostars

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Slide 11 – pure HD core collapse

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Slide 12 – RHD core collapse

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Slide 13 to 16 – RHD core collapse

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Slide 13 to 16 – RHD core collapse

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Slide 17 – Eddington analysis

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