1 Introduction to Monte Carlo Radiation Transfer

The material is taken from [**WWBW2001**] and from [**WWBW2013**].

1.1 Elementary principles

specific intensity	I_ν
radiant energy	dE_ν
surface area	dA
angle	θ
solid angle	$d\Omega$
frequency range	$d\nu$
time	dt
flux	F_ν
cross section	σ
scattering angle	χ $\mu = \cos(\chi)$
mean intensity	J
flux	H
radiation pressure	K

1.2 Example: plane parallel atmosphere

1. emission of photons: select two angles (3D space). In isotropic scattering
   - θ met $\mu = \cos(\theta)$
     - $\mu = 2\xi - 1$ (isotropic scattering)
     - $\mu = \sqrt{\xi}$ (A slab is heated from below. Then $P(\mu) = \mu$)
   - $\phi = 2\pi\xi$
2. propagation of photons
   - sample optical depth from $\tau = -\log(\xi)$
   - distance travelled $L = \frac{\tau z_{max}}{\tau_{max}}$
3. conclusion of emission and propagation

$$\begin{aligned} x &= x + L\sin(\theta)\cos(\phi) \\ y &= y + L\sin(\theta)\sin(\phi) \\ z &= z + L\cos(\theta) \end{aligned} \tag{1}$$

4. Binning: once the photon exists the slab. Produce histograms of the distribution function. Finally, we wish to compute the output flux or the intensity.

2 Asymptotic Preserving Monte Carlo methods for transport equations in the diffusive limit (Dimarco+2018)

3 Fluid and hybrid Fluid-Kinetic models (for neutral particles in plasma edge) (Horsten2019)

The material is mainly taken from [**HorstenNiels2019**].

- Kinetic Boltzmann equation: neutral velocity distribution $f_n(r, v)$
- If you taken into account (e.g. microscopic processes for atomic deuterium) then the kinetic Boltzmann equation becomes

$$v \nabla f_n(r, v) = S_r(r, v) + S_{cx}(r, v) - f_n(r, v)(R_{cx}(r, v) + R_i(r)) \tag{2}$$

- Numerical solution strategies
  - finite differences/volumes/elements :computationally infeasible
  - spectral methods (series expansion of $f_n(r, v)$: not suitable for modelling discontinuties
  - stochatic approach: the whole velocity distribution is discretized by finite set of particles
- from Equation (**??**), the fluid model and the hybrid model is derived.
  - Fluid model: 3 state equations (continuity - momentum - energy) with boundary conditions
    * pure-pressure equation: maximum error of 10 - 28 %
    * with parallel momentum source: error 10 %
    * with ion energy source: error 30 %
  - hybrid model based on micro-macro decomposition

4 Overview of existing (Monte Carlo) radiative transfer codes

4.1 Synthesis codes

As is pointed out in [**PinteChristophe2015CRT**], there are basically two methods to solve the radiative transfer problem: ray-tracing and Monte Carlo methods.

- RADICAL [**RADICAL**] (Ray-tracing, 2D, multi-purpose)
- MULTI [**MULTI**] [**Carlsson1986**] (computer program for solving multi-level non-LTE radiative transfer problems in moving or static atmospheres, very old: Uppsala 1986 - 1995)
- SKIRT [**Camps2015**] (continuum (Monte Carlo) radiation transfer in dusty astrophysical systems, such as spiral galaxies and accretion disks, from Ugent)
- TORUS [**Harries2019**] (Monte Carlo radiation transfer and hydrodynamics code. Adopts 1D, 2D, 3D adaptive mesh refinement. Suitable for radiative equilibrium and creation of synthetic images and SED)
- RADMC-3D [**RADMC3D**] (Monte Carlo code that is especially applicable for dusty molecular clouds, protoplanetary disks, circumstellar envelopes, dusty tori around AGN and models of galaxies. Python interface with Fortran main code)
- TLUSTY and SYNSPEC [**Hubeny2017**], [**Hubeny2017a**], [**Hubeny2017b**].

4.2 Inversion codes

- VFISV
- ASP/HAO
- HeLIx+
- SNAPI (not publicly available, created by Ivan Milic)
- multiple codes available from Instituto de Astrofyiica de Canarias (IAC)
- STiC: the Stockholm inve rsion code