Diagnostic radiative transfer in Astrophysics with RADMC-3D

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Radiative Transfer: Interpreting the observed light
Radiative transfer: Diagnostic tool

Model

Diagnostic radiative transfer

Observation

Forward modeling
Radiative transfer: Diagnostic tool

- **Model**
  - c) $\log(N_{\text{H}_2})$ (cm$^{-2}$)

- **Diagnostic radiative transfer**

- **Observation**

**Forward modeling**

![Image of a solar filament and a molecular spectrograph](image-url)
Radiative transfer: Diagnostic tool

Model

Diagnostic radiative transfer

Observation

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Radiative transfer: Diagnostic tool

Model

Diagnostic radiative transfer

Observation

Forward modeling
Radiative transfer:
Heating, cooling and energy transport

• Astrophysical objects cool by emitting radiation
• That same radiation is the radiation we observe with our telescopes
• Inside the object: Radiation can transport energy from one place to another
• Often linked to hydrodynamics: „Radiation hydrodynamics“
Radiative transfer: Driving photochemistry

• Energetic photons can:
  – photoionize atoms, molecules
  – photodissociate molecules
  – charge dust grains

• This powers a complex photochemical network
Photon-Dominated Regions (PDR)

Example of object with PDRs where photochemistry and photo-ionization play a major role.

Eagle Nebula
In summary:

• Radiative transfer is BOTH about:
  – How radiation affects the object \textit{and}
  – how we can interpret our observations

• In many cases these two are \textit{linked}, so that we cannot interpret our observations without computing how the radiation affects the object.
This Lecture
This lecture:

• **Emphasis:**
  – ...on *diagnostic* radiative transfer

• **We will discuss:**
  – Physics of dust and line radiative processes
  – Equations of radiative transfer
  – Monte Carlo method for dust continuum RT
  – LTE and non-LTE line transfer
  – Hands-on experimentation with RADMC-3D
This lecture:

• Radiative processes:
  – Dust continuum:
    • Dust thermal emission, local radiative equilibrium
    • Scattering off dust particles, polarization
    • Dust opacities, Mie theory, DDA theory
    • Quantum-heated grains, Polycyclic Aromatic Hydrocarbons (PAHs)
  – Gas lines:
    • Atomic lines, recomb. lines, forbidden lines, incl. examples (H, O, O^2+, Ne^+, ...)
    • Molecular lines: rotational, rovibrational, incl. examples (H_2, CO, NH_3, H_2O, ...)
This lecture:

• Radiative processes (cont.):
  – Gas continuum:
    • Bound-free
    • Two-photon
  – Photoionization
  – Photodissociation of molecules
  – Thompson & Compton scattering
This lecture:

• Applications in Astrophysics:
  – Interstellar medium, molecular clouds, star formation
  – Protoplanetary disks
  – Stellar atmospheres
  – Planetary atmospheres
  – Hot gas around compact objects

• Visualization of 3-D model data
Literature:

• A standard book on radiative processes in astrophysics is: **Rybicki & Lightman** “Radiative Processes in Astrophysics” Wiley-Interscience

• For radiative transfer in particular there are some excellent lecture notes on-line by **Rob Rutten** “Radiative transfer in stellar atmospheres”
  [http://www.staff.science.uu.nl/~rutte101/](http://www.staff.science.uu.nl/~rutte101/)

• For stellar atmospheres: pleasantly written book by **Böhm-Vitense** „Stellar Astrophysics Vol. 2: Stellar atmospheres“
Literature:

• In-depth reference work by Mihalas „Stellar atmospheres“
• Allround bible on radiation hydrodynamics by Mihalas & Mihalas „Radiation Hydrodynamics“
• Book on Exoplanetary atmospheres by Seager „Exoplanet Atmospheres“
• Book on radiative transfer in Earth‘s atmosphere (application to e.g. climate research): Wendisch & Yang „Theory of Atmospheric Radiative Transfer“
Literature:

- My own set of lecture notes: [http://www.ita.uni-heidelberg.de/~dullemond/teaching.shtml](http://www.ita.uni-heidelberg.de/~dullemond/teaching.shtml)