Monte Carlo radiative transfer in optically thick regions

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Motivation

Radiative transfer (RT) simulations based on the Monte Carlo (MC) method play a leading role in the calculation of the radiation field and corresponding observable properties of a wide variety of astrophysical objects. Monte Carlo radiative transfer (MCRT) simulations can be used to calculate temperature and intensity maps of simulated objects. However, in the regime of high optical depths, this approach encounters difficulties since a proper representation of the various physical processes can only be achieved by considering high numbers of simulated photon packages. As a consequence, the demand for computation time rises accordingly and thus practically puts a limit on the optical depth of models that can be simulated. On this poster, we present a novel method that aims to solve the problem of high optical depths for MCRT simulations of dusty media.

Background: MCRT

General description

- 3D density distribution of dusty media + sources ⇒ Precise temperature/intensity maps
- Sources emit photon packages ⇒ Simulation of interactions and of the heating process
- Photon paths simulated individually and *randomly* according to their specific probability distribution functions (path lengths, scattering, absorption, and reemission)
- Escaping photons may hit a detector ⇒ Flux measurement
- General problem of high densities: High number of interactions ⇒ Computation time ↑

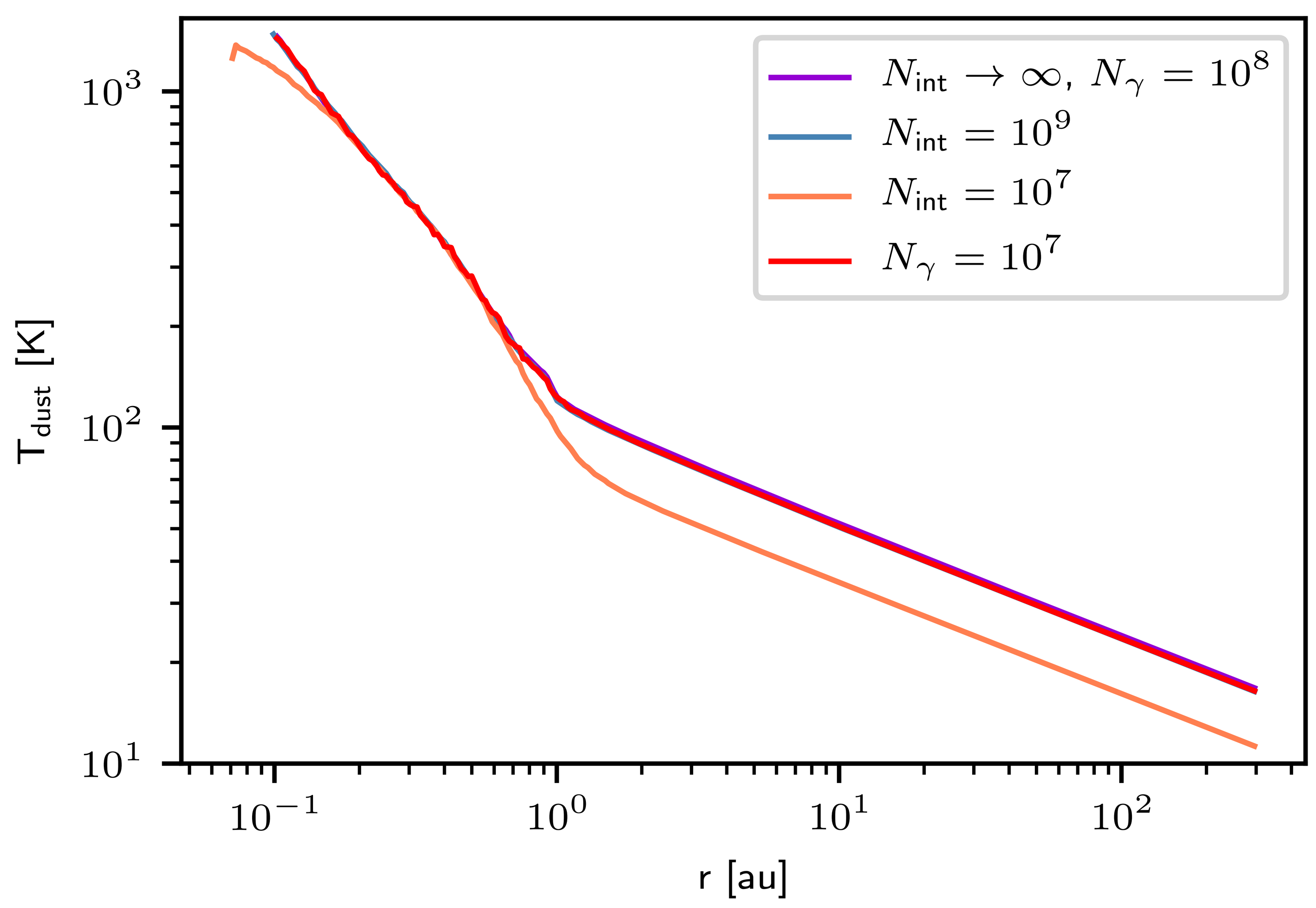
Question

How to perform a proper MCRT simulation that requires an enormous number of simulated interactions N_{int}?

Problem

Problem illustration - Example: Viscously heated circumstellar disk

- Impact of limiting the number of simulated interactions N_{int}
- Setup: Typical viscously heated circumstellar disk (CSD) around typical T-Tauri star



- CSD radial mid-plane temperature profile; varying number of simulated photon packages N_γ and limiting N_{int}; reference model (purple): Unlimited N_{int} with $N_\gamma = 10^8$
- Reduced N_γ: Temperature profile unchanged ⇒ Converged
- Limit N_{int} to 10^9: Temperature profile unchanged ⇒ Converged
- Limit N_{int} to 10^7: Temperature drops significantly
  - Inner-most dense region: Impacts simulated IR observations (MATISSE, PIONIER)
  - Far-out optically thin regions: Impacts simulated mm/submm observations (ALMA)

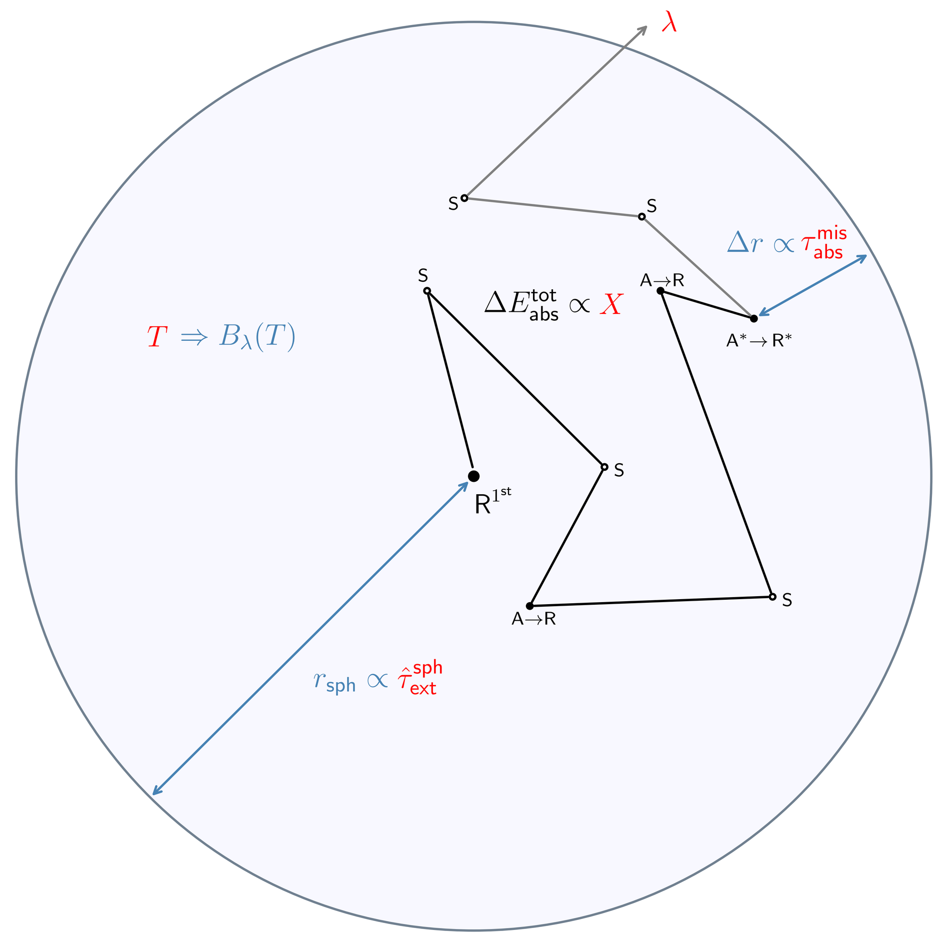
Conclusion:

Impact of too low N_{int} **extends into optically thin regions** and is hard to estimate.
⇒ **A solution to the optical depth problem is crucial!**

Solution

Basic concept @ high optical depths

- Precalculate various paths of photon packages for specific radii
  ⇒ Emission spectra/radiative properties of homogeneous spheres
- Use precalculated spectra to skip costly calculations during real simulations
- Sketch of photon path in sphere: **S**cattering, **A**bsorption, and **R**eemission

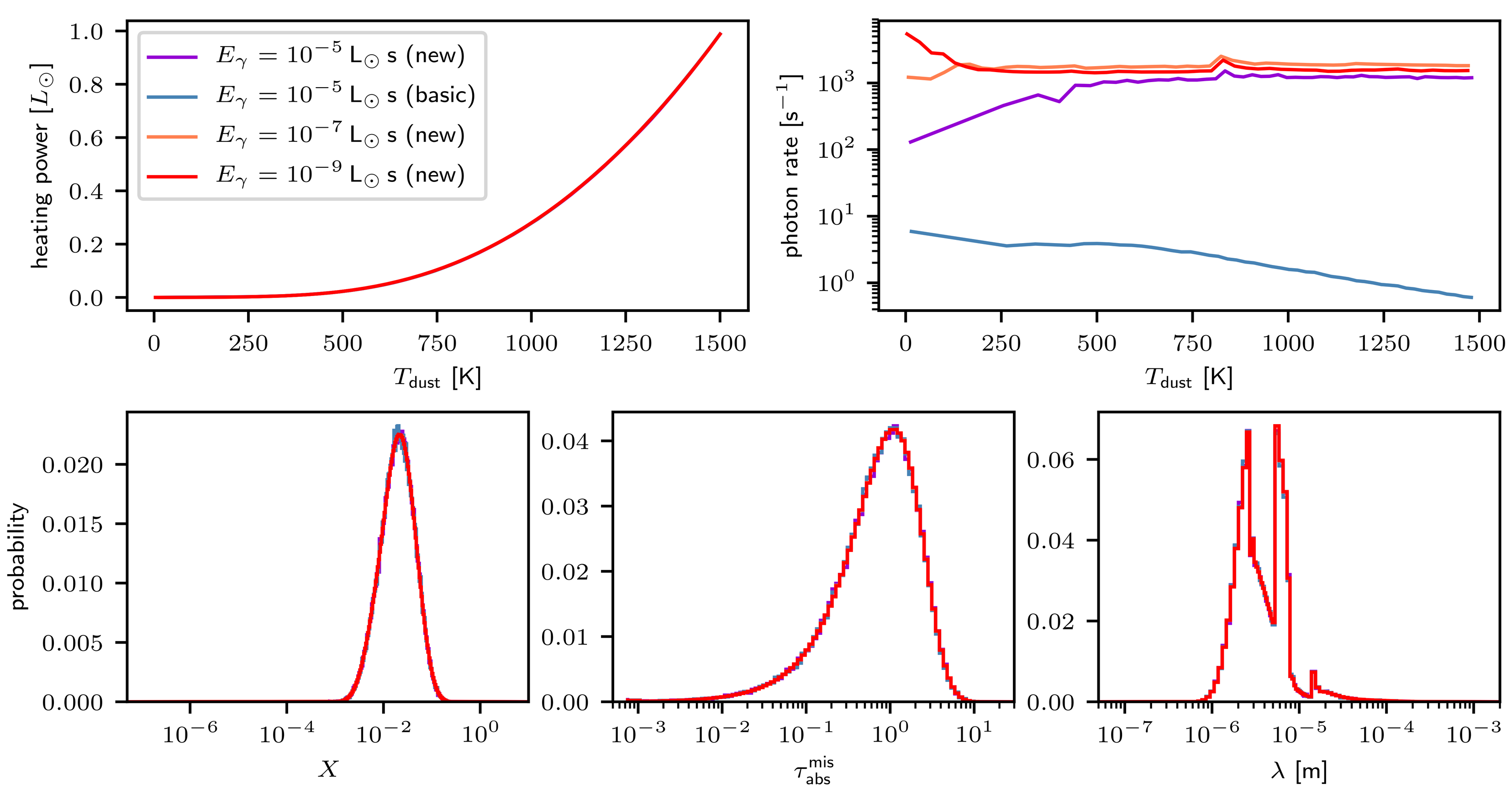


- Precalculate last event of absorption before leaving sphere ⇒ Memory requirement ↓
- *Input:* Temperature T, optical depth radius $\hat{\tau}^{sph}_{ext}$
  Output: Wavelength λ, relative deposited energy X, last point of emission τ^{mis}_{abs}

Testbed

Viability and performance

- Heating up dense homogeneous sphere: 2.7 K to 1500 K and radius $\hat{\tau}^{sph}_{ext} = 3160$
- Compare *basic* MCRT with our *new* method for different photon package energies E_γ



- Heating curves (upper left) and emission spectra (three bottom plots) show agreement
- Performance/speed (upper right) dominated by new method

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Paper reference/link

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Link to paper: A&A