Baltic Astronomy, vol. 16, 92–94, 2007.

EFFICIENT RADIATIVE TRANSFER IN A CIRCUMSTELLAR DISK ENVIRONMENT

M. Baes[1], E. Vidal[1], H. Van Winckel[2], P. Deroo[2] and C. Gielen[2]

[1] *Sterrenkundig Observatorium, Universiteit Gent, Krijgslaan 281 S9, B-9000 Gent, Belgium*

[2] *Instituut voor Sterrenkunde, Katholieke Universiteit Leuven, Celestijnenlaan 200D, B-3000 Heverlee, Belgium*

Received: 2007 January 15

Abstract. We present SKIRT, an efficient 3D Monte Carlo radiative transfer code, designed to treat continuum radiative transfer problems in dusty systems. In particular, we are using SKIRT to investigate the geometry, composition and formation of circumbinary dust disks around post-AGB stars. The main novelty in SKIRT is the use of partly polychromatic photon packages, which allow a very efficient radiative transfer algorithm. We test the accuracy and the numerical requirements of the SKIRT code by comparing its results with recent 1D and 2D benchmark calculations. We demonstrate that the common belief that Monte Carlo radiative transfer is slow, is not valid for state-of-the-art Monte Carlo codes where modern optimization techniques are included. Moreover, the very limited memory requirements of Monte Carlo radiative transfer make high-resolution three-dimensional radiative transfer simulations possible, while this might be more challenging for traditional grid-based codes.

Key words: radiative transfer – stars: circumstellar matter

1. SKIRT RADIATIVE TRANSFER

Circumstellar dust disks are a common phenomenon in various phases of stellar evolution. In particular, the recent homogeneous and systematic study by De Ruyter et al. (2006) strongly suggests that Keplerian dust disks are very common around post-AGB stars. Irrespective of the effective temperature of the central star, the SEDs of all post-AGB stars display a large IR excess with a dust contribution starting at or near sublimation temperature. We have embarked on an extensive study to investigate the geometry, composition and formation of the dust disks around post-AGB stars, using a multi-wavelength observing campaign and a detailed radiative transfer modeling.

As part of this study we present SKIRT, a dust radiative transfer code. It is based on the Monte Carlo algorithm, works in full 3D. The SKIRT code was originally developed to model the observed kinematics of dusty galaxies (Baes & Dejonghe 2002; Baes et al. 2003), but has now been generalized to handle both interstellar and circumstellar environments. Absorption, multiple anisotropic scattering and thermal dust heating and re-emission are taken into account without the need for iteration, even at large optical depths. Several built-in components for the distribution and the optical properties of dust are available. A suite of instru-

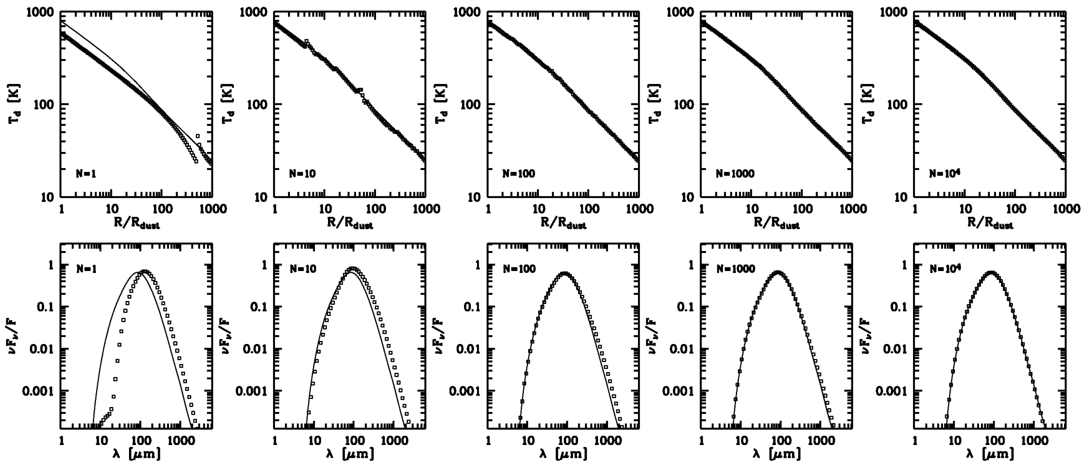

Fig. 1. Demonstration of the efficiency of the SKIRT code to perform LTE radiative transfer calculations. The model is the Ivezić et al. (1997) benchmark results and the different panels represent simulations with increasing total number of photon packages used.

ments are available to measure the radiation field. These instruments mimic real astronomical instrumentation and include imaging and 3D spectroscopic devices.

We have dedicated special care for the optimization of the code. In particular, the main novelty of the SKIRT code is the use of polychromatic photon packages to speed up calculations. These packages contain photons of all wavelengths at the same time. This leads to smooth temperature profiles and high signal-to-noise spectra and surface brightness maps, even at low flux levels (see Figure 1).

2. COMPARISON WITH BENCHMARK RESULTS

We compared the SKIRT code with the 1D and 2D continuum radiative transfer benchmark simulation by Ivezic et al. (1997) and Pascucci et al. (2004). When SKIRT is run in 2D axisymmetrical geometry, we reproduce the dust temperature profiles and spectra easily, both for small and large optical depths (Figure 2). Also, when we run full 3D simulations (i.e., without using the symmetries intrinsic to the models), we reproduce the results easily. The SKIRT code has very modest numerical demands: run times for 2D simulations range between 20 min and 40 min, whereas run times for full 3D simulations range between 4 and 7 hours. The memory requirements are very modest: even full 3D simulations can easily be run on a normal stand-alone computer. Comparing these results with the numerical requirements of the codes used in the Pascucci et al. (2004) benchmark simulations, we conclude that the common belief that Monte Carlo radiative transfer simulations are slow, is outdated.

3. CONCLUSION

The use of polychromatic photon packages in Monte Carlo radiative transfer results in smooth temperature profiles and high signal-to-noise spectra and surface brightness maps. The step to fully 3D simulations is straightforward for Monte Carlo simulations; numerical requirements allow full 3D simulations on reason-

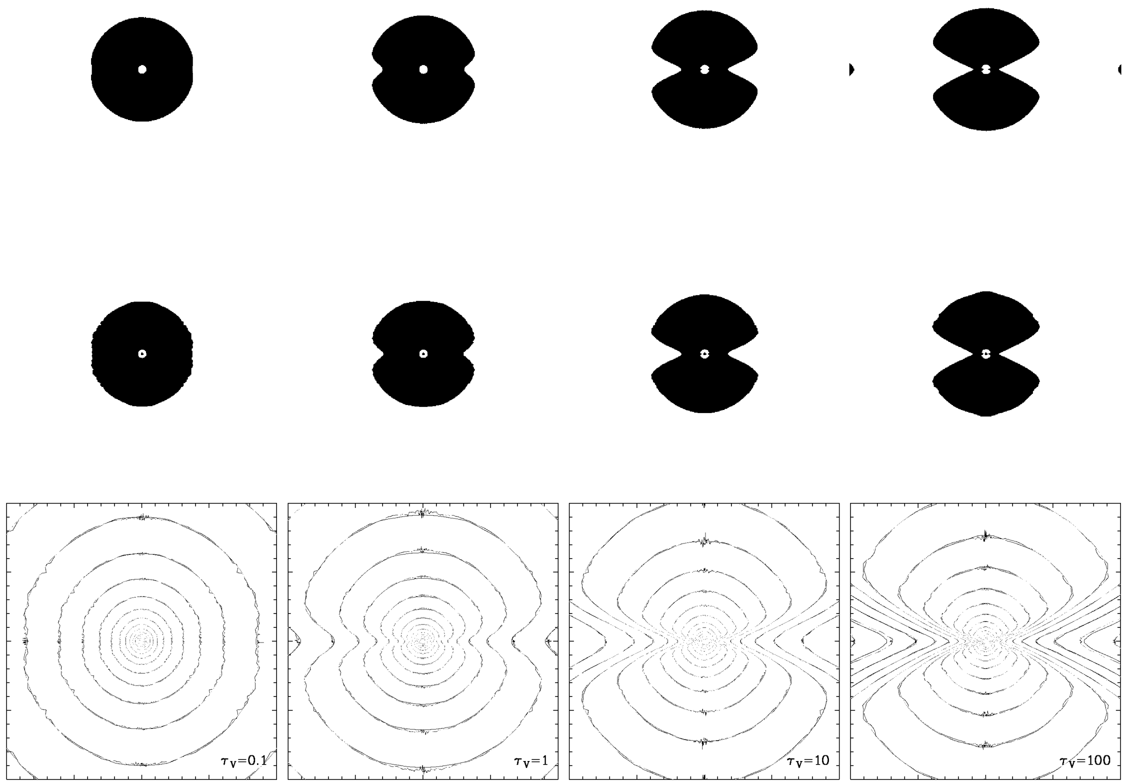

Fig. 2. Pascucci et al. (2004) benchmark test of the SKIRT code. The temperature distribution in the meridional plane as calculated with SKIRT in 2D simulations (top row) is compared with the corresponding benchmark results (central row). The bottom row compares the temperature distribution as calculated in fully 3D SKIRT simulations with the benchmark results. The agreement is obvious.

able time scales on a normal single-processor computer. The Monte Carlo technique is a competitive approach for complicated dust radiative transfer problems, e.g., circumbinary dust disks around post-AGB stars. When modern optimization techniques are taken into account, Monte Carlo radiative transfer codes can be accurate, flexible, economical in numerical requirements and fast.

REFERENCES

Baes M., Dejonghe H. 2002, MNRAS, 335, 441

Baes M., Davies J. I., Dejonghe H. et al. 2003, MNRAS, 343, 1081

De Ruyter S., Van Winckel H., Maas T. et al. 2006, A&A, 448, 641

Ivezić Ž., Groenewegen M. A. T., Men'shchikov A., Szczerba R. 1997, MNRAS, 291, 121

Pascucci I., Wolf S., Steinacker J. et al. 2004, A&A, 417, 793