Radiative transfer through 3D models of dust clouds around AGB-stars

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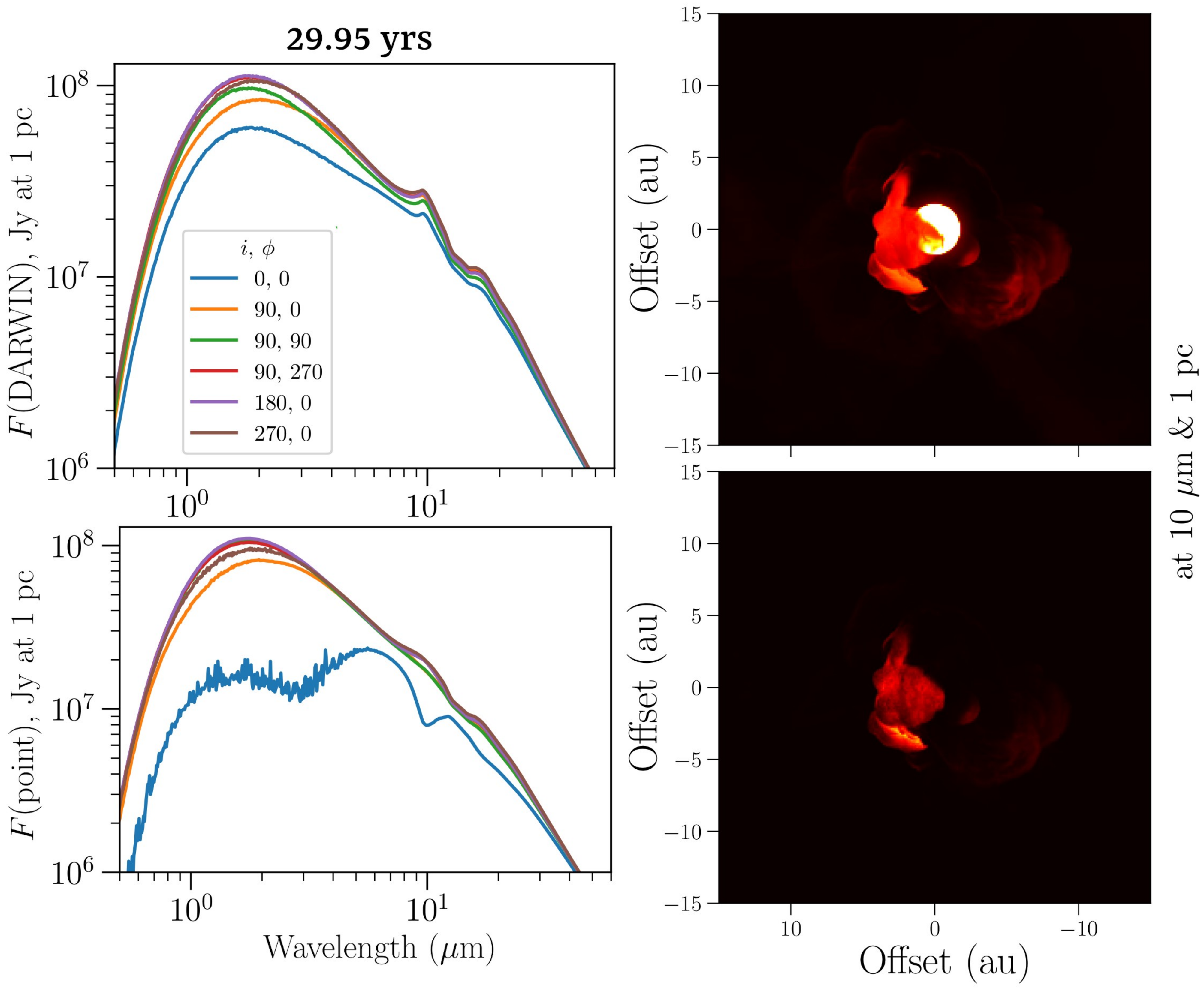
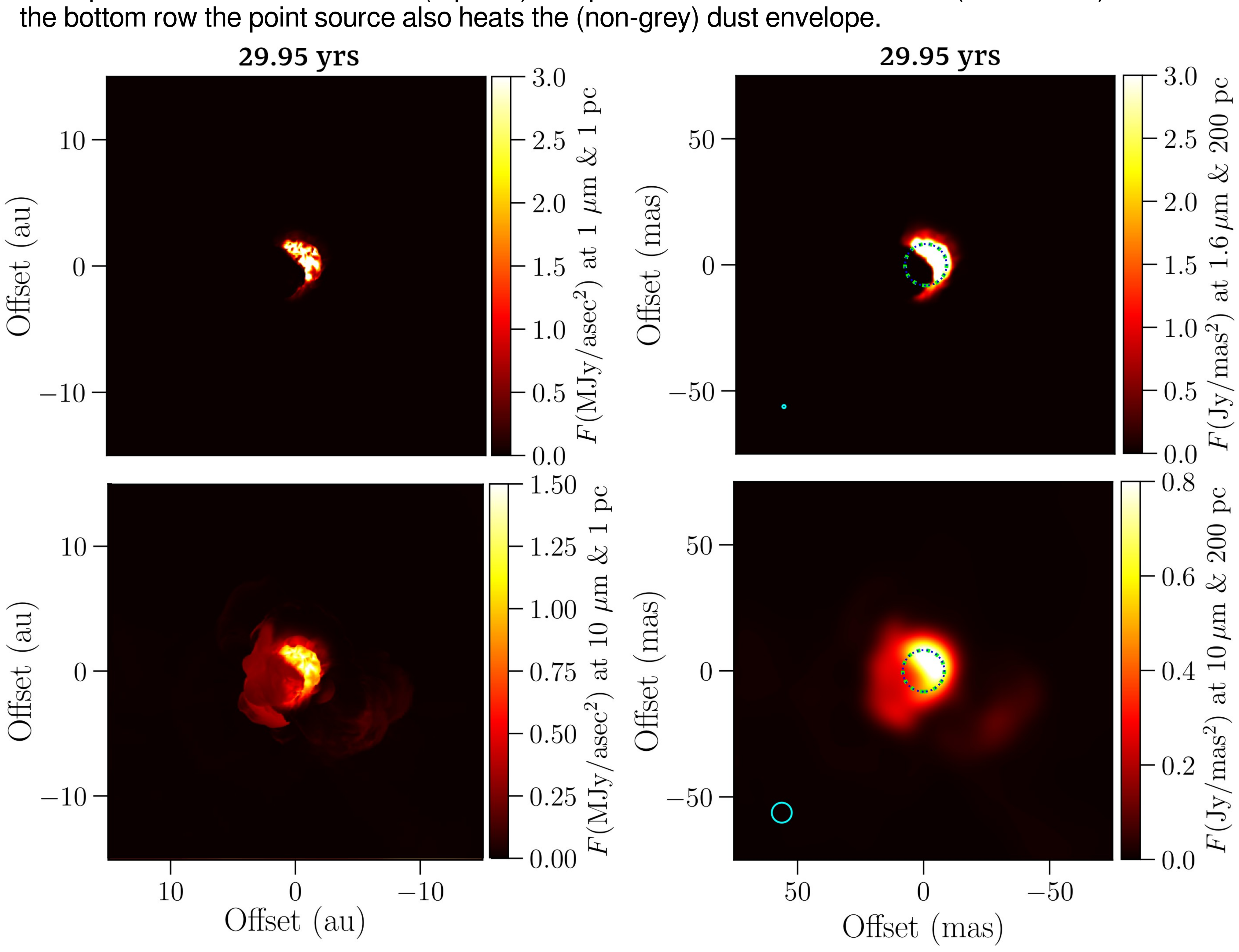
Abstract

During the asymptotic giant branch (AGB) phase, low-to-intermediate mass stars (0.8 - 8 $M_\odot$) are characterized by strong mass loss. Important chemical elements (e.g. carbon) produced in their stellar cores are transported by convection to the surface and by intense stellar winds to the interstellar medium. Crucial for these outflows is the formation of dust. Silicate dust (e.g. Mg_2SiO_4) can form close to the surface of O-rich AGB-stars and is a prime candidate for driving the wind, since grains of sizes between 0.1 to 1 µm experience strong radiation pressure due to scattering.

The EXWINGS team develops global radiation-hydrodynamical (RHD) simulations with CO5BOLD to model the interior of giant stars, outflow of gas, and formation of dust. The first 3D 'star-and-wind-in-a-box' models were recently presented by Freytag & Höfner (2023). Here we present work on using these models to simulate images and spectral energy distributions (SEDs) with the 3D radiative transfer program RADMC-3D. These synthetic observables can be used to study the effects of clumpiness, porosity, and other non-spherical morphologies in circumstellar environments. We also show comparisons with other model setups (e.g. spherical symmetric and point sources) that are common for radiative transfer simulations.



Above: Comparison with symmetric stellar sources. CO5BOLD dust envelope combined with spherical star from DARWIN (top row) and point source from RADMC-3D (bottom row). In the bottom row the point source also heats the (non-grey) dust envelope.



Above: What is observable? *Left:* Simulated images as seen from 1 pc and at 1 and 10 µm. *Right:* Images smoothed with Gaussians to simulate observations. Top image at 1.6 µm with a beam FWHM of 1.3 mas and bottom at 10 µm with a beam FWHM of 7.9 mas. Distance is 200 pc and telescope size is 130 m, corresponding to VLTI's largest UT-baseline.

Model

Stellar radius: ~355 $R_\odot$
Luminosity: ~7000 $L_\odot$
Stellar Mass: 1 $M_\odot$
Effective temperature: ~2800 K
Dust composition: Mg_2SiO_4
Computation box size: 30^3 AU^3

CO5BOLD: COnservative COde for the COmputation of COmpressible COnvection in a BOx of L Dimensions with L = 2, 3. Simulates convection, pulsations, waves, shocks, and winds of various types of stars (Freytag et al. 2012).

DARWIN: Dynamic Atmosphere and Radiation-driven Wind models based on Implicit Numerics. A 1D RHD-code that simulates time-dependant radial structures of stellar atmospheres, grain growth, and stellar winds (Höfner et al. 2016).

Project EXWINGS aims to understand the winds of cool (super)giant stars. *https://www.astro.uu.se/exwings/index.html*

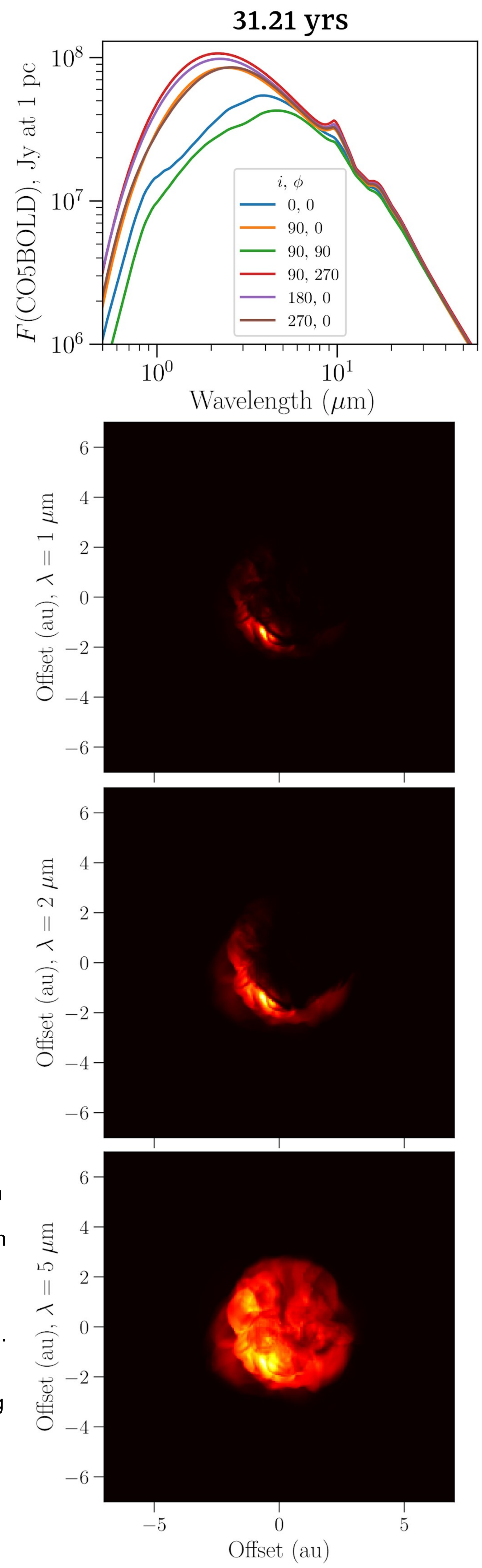
RADMC-3D: Monte-Carlo-based radiative transfer in 3D (Dullemond et al. 2012). *https://www.ita.uni-heidelberg.de/~dullemond/software/radmc-3d/*

Conclusions

- We have developed a method to translate CO5BOLD gas and dust data for radiative transfer simulations with RADMC-3D.
- It is possible to imitate a non-spherical star in RADMC-3D and thus retain spatial effects.
- Replacing the central star with a spherically symmetric star leads to significant differences in resulting images and SEDs.
- Optical interferometres have resolved surface features on AGB-stars (Paladini et al. 2018). Similar resolutions with suitable baseline combinations should also resolve dust clouds forming close to AGB-stars.

Future

- The dust temperature model can be improved to take into account effects from both non-grey dust opacity and non-spherical star.
- Work is ongoing to increase the envelope's spatial size.
- We plan to compare our models directly with high angular resolution observations.



Above: Thick clouds obscure the star. SEDs and images simulated with RADMC-3D of CO5BOLD-data. The SEDs are as observed from 6 different angles. Two angles show significant obscuration with a luminosity decrease from 7200 to 2900 $L_\odot$. The images show 3 wavelengths at the 90-90 angle combination (faintest SED).

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References

Dullemond, C. P., Juhasz, A., Pohl, A., et al. 2012, RADMC-3D: A multi-purpose radiative transfer tool, astrophysics Source Code Library
Freytag, B., Höfner, S. 2023, A&A, 669, A155
Freytag, B., Steffen, M., Ludwig, H. G., et al. 2012, Journal of Computational Physics, 231, 919
Höfner, S., Bladh, S., Aringer, B., & Ahuja, R. 2016, A&A, 594, A108
Paladini, C., Baron, F., Jorissen, A., et al. 2018, Nature, 553, 310

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