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SIMIO-continuum: Connecting simulations to ALMA observations

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Summary

Interferometric observations sample the visibility space of the targeted source. Thus, procedures for image reconstruction are needed to obtain the sky brightness distribution from those observations. Several factors are involved in the detectability of physical features in a reconstructed image, such as the angular resolution of the observation, point spread function, noise level, and the assumptions of the reconstruction algorithm. The most robust way to test the observability of simulated emission features is by taking a simulated model image and reconstructing it with the same algorithms. SIMIO-continuum takes simulated images of continuum emission in millimeter wavelengths and returns the synthetic observation and reconstructed images as if the input model had been observed in the sky with an existing interferometric observation.

The documentation and tutorials give a detailed description of the code functionalities and syntax with publicly available datasets for reproducibility.

Statement of need

Interferometric facilities, such as the Atacama Large sub-Millimeter Array (ALMA), allow us to reach angular resolutions inaccessible by single-dish telescopes. A crucial step in understanding interferometric datasets is generating synthetic observations to compare or predict how physical processes or intensity distributions would be observed.

The Common Astronomy Software Applications package (CASA; McMullin et al. (2007); Emonts et al. (2020); CASA Team et al. (2022)) has the necessary tasks to generate synthetic observations and reconstruct images, and they are very well suited for generating very specific observational setups (Antenna Array configuration, atmospheric conditions, sky coordinates, exposure time, among others). However, generating synthetic observations to mimic existing datasets can be challenging due to the high number of parameters that need to be matched. The SIMIO-continuum package contains all the necessary tools to simplify the process of generating synthetic observations, including routines to modify the geometry and relative distance of a model, and reconstructing synthetic images as if they were actual interferometric observations.

State of the field

SIMIO-continuum is a python-based package for `CASA`, designed to take simulated images of millimeter continuum emission and return a synthetic interferometric observation and its reconstructed images. This functionality is particularly useful when comparing simulated models to archival observations. A common way to do this is by convolving the model image with a Gaussian representative of the angular resolution of the observation. Although this method is quick and easy to apply, it only considers a small step of the imaging reconstruction algorithms. Convolving with a Gaussian does not take into account other factors that could impact the brightness distribution of a reconstructed image (see introduction section of Czekala et al. (2021) and references therein). On the other hand, the CASA task simobserve creates a new observational setup to include the simulated image (e.g., Barraza-Alfaro et al., 2021), but the complexity of this approach can quickly increase if the goal is to reproduce an existing observational setup composed of several projects (e.g., Huang et al., 2018).

Instead of creating a new observational setup as simobserve, SIMIO-continuum uses an existing observation as a template for the synthetic observation. The package takes an input image (containing a millimeter continuum brightness distribution), calculates its visibilities, and then replaces this data in the template observation. This way, the synthetic observation mimics all the technical details of the template (such as the number of antennas, exposure time, frequency coverage, sky orientation, time of observation, and angular resolution). Once the synthetic observation is created, the synthetic reconstructed images are obtained in the same way as for the mimicked observations.

In addition to simobserve, there are other public tools to obtain the visibilities from a model image. For example, the package galario (Tazzari et al., 2018) can calculate the visibilities of a model image in a Python environment, and it is optimized to be used with Markov Chain Monte Carlo (MCMC) algorithms. Another tool is the task fakeobs (Nordic ALMA Regional Center & Olberg, 2021), which can copy the structure of an existing measurement set and replace the data with the visibilities of a model image. SIMIO-continuum is not meant as a visibility fitting tool, as galario, but rather as a tool to generate synthetic observations. Similarly to fakeobs, SIMIO-continuum also mimics the structure of a measurement set and replaces the data with the visibilities of a model image. However, it also includes the option to adjust a model's inclination, rotation, distance, and to generate CLEAN images with minimum user input.

SIMIO-continuum was designed to be easy to use by non-observers while offering the full range of data products for people with different observational expertise. Based on a template observation, astronomers with little or no interferometric experience can obtain synthetic observations and images of their models, allowing for feature-recovery tests with a visibility-based approach.

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