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Wakeflow: A Python package for semi-analytic models of planetary wakes

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Software

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Summary

`Wakeflow` is a Python package for generating semi-analytic models of the perturbations induced by planets embedded in gaseous circumstellar disks. These perturbations take the form of a spiral shock wave (Ogilvie & Lubow, 2002), and are often called a "planet wake" in analogy with that produced by a boat in a lake. Using `Wakeflow`, users may calculate the perturbed density and velocity fields of the gas in the disk. These may be used with radiation transfer codes to generate synthetic observations that map both the gas distribution and the gas kinematics. Comparison with real observations, such as from molecular line emission taken with the Attacama Large Millimetre Array, allows researchers to infer the properties of potential planets as well as the disk itself.

Statement of need

Detecting newly formed planets embedded in their disk is a challenging problem in the field of planet formation. A major area of progress in recent years is the detection of planets by the gravitationally induced disturbance in their host disks. This disturbance, caused by the planet wake, manifests as a deviation in velocity from the bulk flow which may be measured through the Doppler shift of molecular lines (e.g. Perez et al., 2015; Pinte et al., 2018). Such kinematic observations have been accurately reproduced through 3D fluid simulations of the planet-disk interaction, allowing for the inference of planet and disk properties (Pinte et al., 2018, 2019). However, these studies are computationally expensive.

`Wakeflow` eases this computational cost by applying the theory of planet wake generation and propagation (Bollati, Lodato, et al., 2021; Goldreich & Tremaine, 1979; Goodman & Rafikov, 2001; Rafikov, 2002) to create semi-analytic models of planet wakes. `Wakeflow` models are readily created in less than a minute on a modern laptop, as opposed to the hours of supercomputer time needed for 3D hydrodynamical simulations. The relatively low computational cost of `Wakeflow` means that researchers can get an idea of whether planet-disk interactions can explain their observations, and the disk and planet parameters needed, before spending computer time on more detailed simulations.

`Wakeflow` can interface with the radiative transfer code `MCFOST` (Pinte et al., 2006, 2009) in order to create synthetic observations of the semi-analytic models for direct comparison with observed continuum or line emission.

`Wakeflow` is partially adapted from a previous Python code also written by us called `Analytical_Kinks` (Bollati, Fasano, et al., 2021). `Wakeflow` is intended to be a more complete, versatile and easy to use version of that code, and it obeys standard Python packaging conventions. In addition, `Wakeflow` can directly interface with `MCFOST` while `Analytical_Kinks` cannot. At the time of writing, no other open source software packages exist to generate the perturbations induced by an embedded planet in a circumstellar disk using the semi-analytic theory of planet wakes.

Existing scientific publications focusing on detecting the kinematic signatures of planets that have used `Wakeflow` or its predecessor `Analytical_Kinks` include Bollati, Lodato, et al. (2021), Calcino et al. (2022) and Teague et al. (2022).

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`Wakeflow` relies on the following scientific Python packages: `NumPy` (Harris et al., 2020), `Matplotlib` (Hunter, 2007), `SciPy` (Virtanen et al., 2020) and `Astropy` (Astropy Collaboration et al., 2022).

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