1 Tstrippy

This project is built on `f2py`, which allows integration between Fortran and Python. The core motivation behind this choice is performance: Fortran, as a compiled language, provides significantly faster execution for numerically intensive tasks, while Python—especially within Jupyter notebooks—offers a convenient environment for development, experimentation, and visualization. `F2py` stands for *Fortran to Python* [Peterson, 2009], and it is included as a module within NumPy [NumPy Developers, 2025, Harris et al., 2020]. The name of the project, `tstrippy`, stands for `T`idal `Strip`ping in `P`ython.

`F2py` supports Fortran 77, 90, and 95 standards, so we chose to write the code in Fortran 90 to make use of its support for *modules*. In Fortran, a module encapsulates data and subroutines in a manner somewhat analogous to classes in object-oriented programming. However, Fortran modules do not support inheritance, and only a single instance of a module can exist at a time—unlike classes, which can be instantiated multiple times.

`Tstrippy` package is structured around five core Fortran modules, each responsible for a distinct aspect of the simulation:

- `integrator`: This is the central module of the code. It stores particle positions and velocities, computes forces, and evolves the system forward in time. It also handles the writing of output data at specified intervals and interfaces with all other modules in the code.

- `potentials`: This module defines the analytical potentials used to compute gravitational forces. It currently supports several models, including `Plummer`, `Hernquist`, `AllenSantillian`, `MiyamotoNagai`, the bar model `LongMuraliBar` from Long and Murali [1992], and the composite model from `pouliasis2017pii` [Pouliasis et al., 2017]. This module can also be called in Python, allowing users to call potential functions directly, e.g., for computing energies during post-processing.

- `hostperturber`: This module handles the host globular cluster. It stores its orbit (i.e., timestamps, positions, and velocities) and ensures its synchronization with the simulation's internal clock. It computes the gravitational influence of the host cluster on each star particle. This is an internal module only.

- `perturbers`: Similar in function to `hostperturber`, this module supports additional perturbing clusters. It allows for the inclusion of multiple perturbers and computes their collective force on each particle. If object-oriented programming were available in Fortran, both this module and `hostperturber` would naturally inherit from a shared parent class. This module only uses the positions, masses, and characteristic radii of the other perturbers. The velocities are not imported.

- `galacticbar`: This module stores parameters for the Galactic bar, including the polynomial coefficients for its angular displacement as a function of time:

  $$\theta(t) = \theta_0 + \omega t + \dot{\omega} t^2 + \ddot{\omega} t^3 + \dots$$

  It performs transformations into the rotating bar frame, computes the forces in that frame, and then transforms the forces back to the Galactocentric reference frame.

This modular structure makes it straightforward to extend the code by adding new physics in the form of additional modules.

To make the package installable and easy to distribute, I initially followed the guide by Bovy [2025], which describes how to create a Python package using `setuptools`—the standard build system in the Python ecosystem. However, compatibility between `setuptools` and `f2py` was broken starting with NumPy $>$ 1.22 (released June 22, 2022[1]) and Python $>$ 3.9.18 (released June 24, 2024[2]). This meant that Fortran extensions could only be compiled using deprecated versions of both. These older versions of NumPy were also not compatible with Apple's ARM-based M1 and M2 processors, rendering the code unusable on modern Mac systems.

This limitation stemmed from the deprecation and eventual removal of `numpy.distutils`, the tool that previously enabled seamless integration of Fortran code in NumPy-based packages. As of NumPy 1.23

[1] `https://github.com/numpy/numpy/releases/tag/v1.22.0`
[2] `https://www.python.org/downloads/release/`

and later, `numpy.distutils` was deprecated, and with NumPy 2.0, it was removed entirely. The NumPy developers recommended migrating to `meson` [Meson Developers, 2025] or `Cmake`.

To address these issues, I migrated the build process to `meson`, a language-agnostic build system capable of compiling Fortran, C, and Python extensions across architectures. This eliminated compatibility problems and made the build process architecture-independent. The build system now automatically detects the system architecture and compiles accordingly.

The code is fully open source and available on GitHub.[3] To support users, I created documentation hosted on `readthedocs.io`[4], which includes working examples and basic usage guides. A minimal test suite, written using `pytest`, is also included. While not exhaustive, the tests ensure that core functionality remains intact as the code evolves. In the next section, I present a minimal example of how the user may use the code within a python script.

1.1 Minimum example

If the package is properly installed on the system, it can be imported at the top of any Python script:

```
import tstrippy
```

Next, the user must load or define the initial conditions. The code provides:

- The masses, sizes, and kinematics of the globular cluster catalog from Baumgardt and Hilker [2018];
- The galactic potential parameters for model II of Pouliasis et al. [2017]; and
- A galactic reference frame.

```
GCdata      = \
    tstrippy.Parsers.baumgardtMWGCs().data
MWparams    = \
    tstrippy.Parsers.potential_parameters.pouliasis2017pii()
MWrefframe  = \
    tstrippy.Parsers.potential_parameters.MWreferenceframe()
```

The user must then select the system to integrate. For example, to integrate the orbits of observed globular clusters, one must convert the ICRS coordinates to a Galactocentric frame using `astropy` and the provided MW reference frame. Alternatively, to simulate a star cluster, one can generate a Plummer sphere:

```
xp,yp,zp,vxp,vyp,vzp=\
tstrippy.ergodic.isotropicplummer(G, massHost, halfmassradius, NP)
```

Here, `NP` is the number of particles, `halfmassradius` is the system's half-mass radius, `massHost` is the total mass of the Plummer sphere, and `G` is the gravitational constant. All values must be in the same unit system.

The integrator must then be initialized. All parameters are passed via lists that are unpacked at the function call. Here is an example of initializing the integrator for a stellar stream in a potential that includes a rotating galactic bar:

```
tstrippy.integrator.setstaticgalaxy(*staticgalaxy)
tstrippy.integrator.setinitialkinematics(*initialkinematics)
tstrippy.integrator.setintegrationparameters(*integrationparameters)
tstrippy.integrator.inithostperturber(*hostperturber)
tstrippy.integrator.initgalacticbar(*galacticbar)
tstrippy.integrator.setbackwardorbit()
```

- `setstaticgalaxy` specifies the static potential model and passes its parameters.
- `setinitialkinematics` provides the initial positions and velocities of the particles.
- `setintegrationparameters` defines the initial time, timestep, and number of steps.
- `inithostperturber` specifies the globular cluster's trajectory and mass as a function of time.

[3] `https://github.com/salvatore-ferrone/tstrippy`
[4] `https://tstrippy.readthedocs.io/en/latest/`

- `initgalacticbar` defines a rotating bar. It takes the name of the bar model, potential parameters, and spin parameters.
- `setbackwardorbit` reverses the velocity vectors and sets the internal clock to count down: $t_i = t_0 - i \cdot \Delta t$. For the usecase presented in this work, `setbackwardorbit` is used for computing the globular cluster orbits and not for the star-particles.

The user can choose between two output modes during integration:

```
tstrippy.integrator.initwriteparticleorbits(nskip,myoutname,myoutdir)
tstrippy.integrator.initwritestream(nskip,myoutname,myoutdir)
```

Conceptually, these represent two output paradigms:

- `initwriteparticleorbits` saves the full orbit of each particle to an individual file.
- `initwritestream` saves full snapshots of all particles at selected timesteps.

Both functions take:

- `nskip`: number of timesteps to skip between outputs;
- `myoutname`: the base file name;
- `myoutdir`: the output directory.

The output files will be named like: `../dir/temp0.bin`, `../dir/temp1.bin`, ..., up to `../dir/tempN.bin`, where $N = N_{\text{step}}/N_{\text{skip}}$. Note that the files are written in Fortran binary format. Although `scipy.io.FortranFile` can read them, I use a custom parser based on `numpy.frombuffer` to avoid the SciPy dependency.

Once all parameters are set, the user can proceed with integration using one of two methods:

Full orbit integration (in memory)

```
xt,yt,zt,vxt,vyt,vzt=\
    tstrippy.integrator.leapfrogintime(Ntimestep,nObj)
timestamps=\
    tstrippy.integrator.timestamps.copy()
```

`leapfrogintime` stores the full orbit of each particle in memory. This is useful for a small number of particles or short integrations—e.g., rapid parameter studies in a notebook. However, for large simulations it can be prohibitively memory-intensive. For instance, integrating all globular clusters at high time resolution might require:

$$7 \times N_p \times N_{\text{step}} \times 8 \text{ Byte} \approx 450 \text{ GB} \tag{1}$$

if $N_{\text{step}} \approx 10^7$. This will likely exceed system RAM.

Final state only

```
tstrippy.integrator.leapfrogtofinalpositions()
xf   = tstrippy.integrator.xf.copy()
yf   = tstrippy.integrator.yf.copy()
zf   = tstrippy.integrator.zf.copy()
vxf = tstrippy.integrator.vxf.copy()
vyf = tstrippy.integrator.vyf.copy()
vzf = tstrippy.integrator.vzf.copy()
finaltime=tstrippy.integrator.currenttime.copy()
```

`leapfrogtofinalpositions()` performs the integration but only returns the final phase-space coordinates. These arrays must be copied before deallocating memory:

```
tstrippy.integrator.deallocate()
```

Deallocating is necessary to avoid memory leaks or crashes in Jupyter when rerunning code cells.

1.2 Was it worth developing my own code?

Why did I get to meson? It was recommended to me by co-pilot. I am aware that others exist. However, the build eco-system is large. I found one that worked, and I kept going not feeling the need to explore all options.

Why use f2py instead of doing something like cython or C++ to python? Inheritence. The first version of the code was built in fortran, so I kept going with this.

- now I want to build on some reflection points. Was it worth building this code? I want to make a list of pro's and cons:
- *pro.* I don't know apriori if another code supports that I am after. I remember trying to implement a particle spray method in *Galpy.* However, I wanted to use our potential model. The `AllenSantillian` halo model is not standard and was not implemented in *galpy.* It can be implemented. However, the user must create a python class for this. I did this, however, custom potentials that are not combinations of existing potentails are not supoprted with C++, and the resulting computations are thus really slow.
- *pro* so by writing my own code, I ensured that *I knew what I was doing.* This was the most practical aspect of writing the code myself, it is not a black box (mostly, I don't know if I will ever truly understand the compilation process).
- *con.* You either have to reinvent the wheel, or just not do something. There are many times where I wanted to use the actions. However, the implementation was daunting. In somecases, I turned to Galpy or Agama for some quick analyses.
- *con.* on the same note, I struggle with implementing exponential disks or flattened halos. At first, I tried to solve for the orbits of stars within those systems using *elliptical coordinates.* This is great for describing the mass distribution in terms of just one variable. However, the basis vectors change in direction and size, requiring the Christoffel symbols. I hadn't realized this at first and spent much time wondering why my orbits were diverging. In the end, I realized I either had to implement the Christoffel symbols for the integration and then transform back to cartesian coordinates, or perform a basis function expansion, which is the standard practice in the field. However, at that point, I decided to leave code development on the side and start and analyzing other simulations.
- *pro*: someone else is using my code for answering adjacent scientific questions that my code is adapted for.
- *pro*: I like this line of work. This project pushed me to use the best practices of GitHub integration, documentation, and reusability. Perhaps I could be a valuable member of another project some day and not just be a developer of one.

References

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